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GEOLOGICAL SURVEY OF QUEENSLAND
(A. K. Denmead, M.Sc., Chief Government Geologist)

PUBLICATION No. 317

THE GEOLOGY AND MINERAL RESOURCES OF THE CHILLAGOE AREA

By F. DE KEYSER, Bureau of Mineral Resources,

and K. W. WOLFF, Geological Survey of Queensland.

Also issued as Bureau of Mineral Resources, Geology and Geophysics, Australia, Bulletin No. 70

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SUMMARY

This Bulletin presents the results of five months' fieldwork carried out by a joint geological party from the Bureau of Mineral Resources and the Geological Survey of Queensland in 1958, and incorporates subsequent scattered field observations in more recent years.

The area investigated is covered by the three One-Mile Sheets of Chillagoe, Mungana, and Almaden, and forms the north-western part of the Atherton 1:250,000 Sheet area, North Queensland. Metamorphosed and migmatized Precambrian schist, gneiss, and muscovite granite in the west are separated from folded Palaeozoic geosynclinal sediments by a large fault. The geosynclinal deposits are represented by Upper Silurian to Lower Devonian formations with mixed shelf facies, and, farther east, by the eugeosynclinal flysch sediments of the Middle to Upper Devonian Hodgkinson Formation. Remnants of unconformable lacustrine or estuarine sediments, probably Carboniferous, are also exposed.

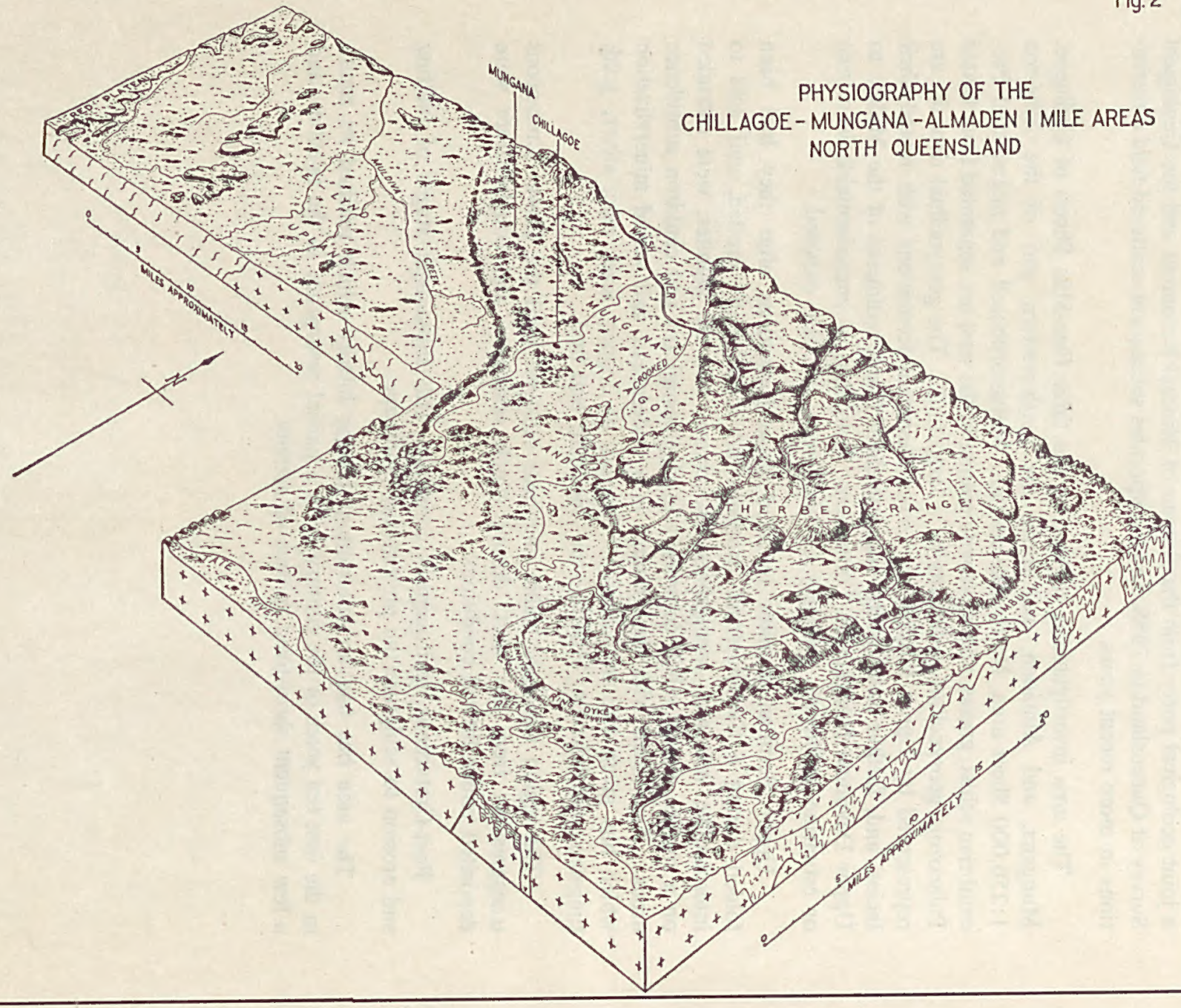
Upper Permian granites intruded these formations after they had been folded during a Carboniferous orogeny and subsequently eroded, and acid to intermediate volcanics, comagmatic and coeval with the granites, were extruded on a surface of low relief, commonly in ring complexes and cauldron subsidence areas. Associated with the granites is a widespread and varied mineralization which has given rise to numerous deposits of copper, lead, zinc, silver, gold, tungsten, molybdenum, bismuth, tin, fluorspar, and iron.

The region remained stable and near sea-level until the Lower Cretaceous transgression from the west, during which sandstone and conglomerate were deposited under littoral conditions.

Post-Cretaceous epeirogenesis combined with subsequent stages of faulting and erosion to sculpture the present-day landscape.

The area has had an intermittent mining history which reached its zenith in the first ten years of the century, with a partial resurgence in the twenties, and a few subsequent short-lived spasms of activity.

Fig. 2


PHYSIOGRAPHY OF THE
CHILLAGOE - MUNGANA - ALMADEN 1 MILE AREAS
NORTH QUEENSLAND
MUNGANA
CHILLAGOE
MULLIGAN CREEK
WALSH RIVER
MUNGANA CHILLAGOE UPLAND
CROOKED CK
FEATHER BED RANGE
ALMADEN
TENNYSON
OYKE
DIMBULAH PLAIN
MILES APPROXIMATELY
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INTRODUCTION

Situation and Access

An area of about 1800 square miles is covered by the combined Mungana, Chillagoe, and Almaden 1-mile Sheets, and is contained within latitudes 17° and 17°30′ South and longitudes 144° and 145° East (Fig. 1). The settlements of Chillagoe, Almaden, and Petford, now virtually ghost towns of the old mining days, are connected with Cairns by rail and road. Chillagoe is 85 miles flying distance from Cairns, or 145 miles by road. A branch railway line to Mount Garnet (outside the area south of Petford) has been abandoned since 1961, and a weekly service to Mungana has also been discontinued since this settlement became deserted in 1961. Another line, branching off at Almaden, leads to Forsayth, outside the area mapped.

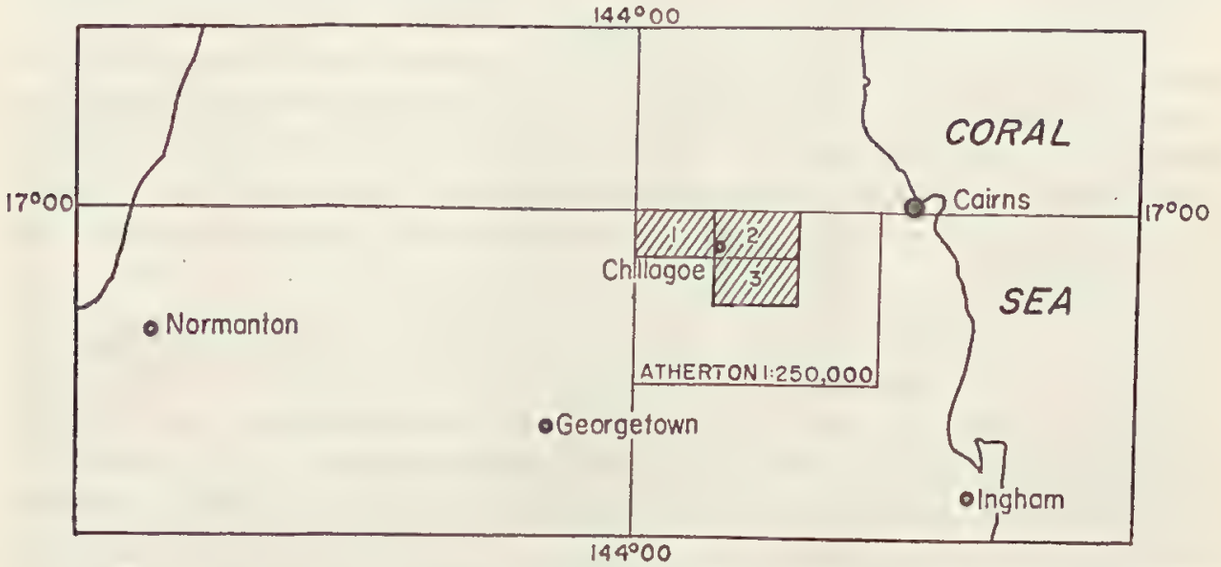


Fig. 1. The area mapped: 1. Mungana 1-mile Sheet; 2. Chillagoe 1-mile Sheet; 3. Almaden 1-mile Sheet.

Air-strips suitable for light aircraft are maintained at Chillagoe and at the Sunnymount battery.

Climate

The Chillagoe district lies within the semi-arid belt immediately west of the tropical coastal humid zone of North Queensland, and has a dry winter and wet summer. The average annual rainfall of 30 to 40 inches falls mostly in the summer months (January to March); the monthly average during the winter is less than an inch.

The mean daily temperature ranges from about 60° in the winter to 80° during the summer.

Geography (Fig. 2)

Both altitude and relief grade from moderate in the east to low in the west. Generally speaking, the area lies on the gentle slope from the Atherton Tableland

in the east—outside the area—to the low sandy plains and alluvials around the Gulf of Carpentaria to the west. Within the boundaries of the area mapped this general tilt is apparent from the differences in altitude between Batcha siding in the south-east (1971 feet) and the Cardross area in the north-west (600 feet). The maximum elevations are found in the rugged Featherbed Range, where the highest summits are an estimated 2500 to 3000 feet above sea-level. The lowest points, at about 600 feet above sea-level, occur where the Walsh River leaves the area in the north-western part of the Mungana Sheet.

The landscape is controlled to a marked degree by lithology and by structure. Gently undulating country is characteristic of the Dargalong Metamorphics in the west (though the gneisses and granulites form some rough surfaces in the south-western parts). The deeply incised, rough, uninhabited, and stony massif or tableland of the Featherbed Range is built up of the massive porphyries of the Featherbed Volcanics. The Chillagoe Formation and much of the granite have developed moderately flat country in which the limestone crops out as jagged bluffs and ridges 100 to 300 feet high; chert ridges, on the other hand, are typically smooth and rounded. The western edge of the Mungana Sheet area is characterized by the horizontal beds of Cretaceous sandstone of the Red Plateau and its fringe of mesas and buttes.

The Chillagoe district is drained by the Walsh and Tate Rivers, which ultimately join the Mitchell River and flow into the Gulf of Carpentaria. The Walsh River is perennial most years; most of the other watercourses are dry during the winter or, at the most, maintain a chain of disconnected waterholes (e.g., Tate River, Emu Creek, Crooked Creek). In the Chillagoe limestone belt and at the base of the Cretaceous sandstone mesas springs can be found, some of which have enough discharge to maintain a permanent flow or trickle: the Chillagoe Creek is a good example.

Fieldwork

The survey was undertaken:

a. as part of the regional geological mapping of the Atherton 1:250,000 Sheet;

b. to locate and investigate the mineral deposits;

c. to map in detail the Chillagoe Formation.

The mapping was carried out between April and October, 1958, by a party comprising two geologists of the Bureau of Mineral Resources (F. de Keyser and M.B. Bayly) and a geologist of the Geological Survey of Queensland (K. W. Wolff). Air photographs taken by the R.A.A.F. at a scale of about 1:47,000 were used for navigation on the ground and as a base for the compilation of field data; air photographs at a scale of 1:12,000 were available for the detailed work in the environs of Mungana and Chillagoe. The results were plotted on planimetric maps (1:47,000) provided by the Division of National Mapping.

Various independent field observations made during more recent years by geologists of the Bureau of Mineral Resources have added to the clarification of outstanding problems.

Authorship.—The Summary, Introduction, and Regional Geology of this Bulletin have been written by F. de Keyser; the Economic Geology is based on an unpublished report by K. W. Wolff (1959), later revised by F. de Keyser. The Appendices are the work of K. W. Wolff, who also compiled Table 2.

Previous Investigations

Since 1887, when the first ore deposits became known, much has been published on the mineral occurrences in the area, but comparatively little attention was given to the regional geology.

Among the more important publications on various mining centres are those by Ball on Wolfram Camp (1919a, 1920), Bamford Hill (1914b), and Cardross (1917a); by Jensen on the mines in the Mungana-Almaden area (1920a,b,c; 1941); by Jack on many mines in the Chillagoe and Koorboora area (1891); by Morton & Ridgway on Wolfram Camp (1944b); and by Broadhurst on the Mungana and Chillagoe districts (1952, 1953). The role played by the various mining companies in the investigations of the area will be discussed in the chapter on Mining History (page 53).

The most comprehensive geological studies were made by Jensen (1923, 1941) and, in the more restricted area between Mungana and Chillagoe, by Broadhurst (1952). A good account of the Dargalong Metamorphics was given in a report by Ball (1917a).

REGIONAL GEOLOGY

STRATIGRAPHY

Broadly speaking, the Chillagoe district is situated along the western periphery of the Palaeozoic Tasman Geosyncline on the borders of the Precambrian basement, where shelf conditions once prevailed. After being folded, the Palaeozoic sediments were intruded by Upper Permian granites and covered by concomitant volcanics.

The following geological units are distinguished (see Table 1 for more detail):

1. Precambian schist, gneiss, granulite, migmatite, and amphibolite of the Dargalong Metamorphics. These occupy most of the Mungana Sheet area.
2. Upper Silurian to Lower Devonian shelf sediments of the Chillagoe Formation (mixed facies) and the Mount Garnet Formation (clastic facies).
3. The Middle to Upper Devonian Hodgkinson Formation. This unit, with its thick pile of greywacke and siltstone, may be compared to a geosynclinal flysch facies, and crops out in the extreme north-eastern and south-eastern parts of the area mapped.

4. Remants of quartz sandstone and siltstone, probably Carboniferous, in the Koorboora and Boxwood areas, Almaden Sheet, may represent molasse-type deposits, and appear to overlie the older formations unconformably.
5. Acid to intermediate Upper Permian granites—the Herbert River and Elizabeth Creek Granites and their differentiates—intrude all previous formations, and occupy large tracts of the Chillagoe and Almaden Sheet areas.
6. Large volumes of concomitant volcanics — flows, pyroclastics, and welded tuffs — form the Boxwood, Nychum, and Featherbed Volcanics and the Doolan Creek Rhyodacite. They are widely distributed in the Chillagoe and Almaden Sheet areas.
7. Horizontal blankets of Lower Cretaceous sandstone — the Wrotham Park Sandstone — overlie the Dargalong Metamorphics with a strong angular unconformity, and form the Red Plateau, part of which occupies the western edge of the Mungana Sheet area.

Some of these units are represented on the photo stereo-pair of Plate I.

Precambrian

The Dargalong Metamorphics

The Dargalong Metamorphics, first named by Skertchly (1899) and most comprehensively described by Ball (1917a), crop out over most of the area covered by the Mungana 1-mile Sheet. They are much folded and faulted, and are overlain by a blanket of Cretaceous sandstone in the west and by the Nychum Volcanics in the north. They are separated from the Chillagoe Formation in the east by a large fault—the Palmerville Fault. Upper Permian granite intrudes the metamorphics in places. The type area for the formation is the old mining centre of Dargalong, south-west of Chillagoe.

Quartz-mica schist, gneiss, augen gneiss, granulite, muscovite pegmatite, quartzite, amphibolite, migmatite, and muscovite granite are the types of rock normally exposed (Plate 2). With the exception of the amphibolites, they grade into one another.

The quartzite, mica schist, and gneiss are generally metamorphosed sediments, although some gneiss appears to be intrusive. The quartzite is generally a slabby, thoroughly recrystallized white to grey or—more rarely—dark rock, and has its greatest extent in the north-west. Rare examples of preserved ripple-marking have been found. The mica schist is silvery-grey and commonly crenulated and intricately folded, with amplitudes ranging from a few millimetres to several feet. Muscovite is generally more abundant than biotite, though biotite-rich rocks poor in muscovite are not uncommon.

With decreasing mica content and increasing grain size the marked schistosity is lost, and the rock grades into gneiss and granulite. Some gneiss contains conspicuous augen (Pl. 2, fig. 2) of untwinned potash feldspar, 1 to 3 inches across, set in a micaceous quartz-plagioclase matrix.

TABLE 1

STRATIGRAPHY OF THE CHILLAGOE, MUNGANA, AND ALMADEN 1-MILE SHEET AREAS, NORTH QUEENSLAND

	Unit and Symbol	Thickness	Lithology	Distribution	Structure and Topography	Age, Palaeontology and Correlation.	Relationships	Remarks
CAINOZOIC	Qa	?	Soil, alluvial, sand and silts.	Scattered patches along main rivers, and in Mungana, Chillagoe-Almaden area.	Level ground.	Recent, probably grading back into Pleistocene and perhaps Tertiary, in places.	Unconformable veneer over older formations.	Some alluvial tin in Koorboora area and along Spinifex and Halpin Creeks, Batcha.
	Czs	?	Residual sand cover.	Mainly along Tomato Creek (N.W. of Mungana Sheet) and over granite south of Oakey Creek, south of Tennyson Ring Dyke.	Level sandy ground	Possibly Tertiary to Recent.	Unconformable blanket over Cretaceous sandstone and Permian granite.	Derived from disintegrated Cretaceous sandstone and Permian granite.
MESOZOIC	Wrotham Park Sandstone Klw	330 ft. max.	Cross-bedded sandstone, pebbly sandstone, and conglomerate. Some shale.	Western edge of Mungana 1-mile Sheet area.	Forms mesas and eastern fringe of Red Plateau.	Neocomian or Aptian. Probably to be be correlated with Gilbert Formation	Unconformably overlying Dargalong Metamorphics.	
	Undifferentiated Pzu	—	Coarse biotite granite, biotite-muscovite granite; grey biotite granite; fine-grained dark hornblende diorite.	In places within the Mungana 1-mile Sheet area, forming isolated stocks.	Usually hilly.	Probably Permian, and equivalent to the Herbert River, Almaden and Elizabeth Creek Granite.	Intrudes the Dargalong Metamorphics.	
	Elizabeth Creek Granite. Pgz	—	?a) Grey to pink hornblende-bearing biotite microgranite.	Granite massif south of Petford and Lappa Junction.	Jointed massif.	Probably Upper Permian.	Intrudes S-Dm and probably part of Pf. Is probably younger than Pgz^b, Pgz^c, Pgh, Pga.	Possibly represents contaminated Pgz. Usually contains allanite, as accessory.
	,,	—	b) Pink, leucocratic, biotite granite and adamellite; fine-grained and leuco-granite; coarse pink granite porphyry.	Mainly south of Tennyson Ring Dyke and along Tate River. Almaden 1-mile Sheet area. Smaller outcrops at Wolfram Camp and north of Almaden.	Varied topography: sand-covered low areas with scattered tors; and jointed hilly exposures.	Upper Permian; possibly grading into Lower Triassic.	Intrudes Pgh, S-Dm, part of Pf, and Cr.	All Pgz varieties have introduced tin, tungsten, molybdenum, bismuth, and fluorite mineralization.
	,,	—	c) Very coarse, pink-red, leucocratic alkali granite.	Along Halpin Creek south of Batcha, and along northern rim of Boxwood Ring Complex, Almaden 1-mile Sheet area.	Sand-covered tor and boulder areas.	Upper Permian.	Older than Pgz^a and probably Pgz^b; older than part of Pf (Tennyson Ring Dyke).	
	Featherbed Volcanics Pf	At least 2000 ft. for the total of Pf, a,b,c.	a) Massive, dark-grey or green rhyolite to dacitic ignimbrites.	Largest portion of Chillagoe 1-mile Sheet area, and central-northern part of Almaden Sheet area.	Forms the high, rugged, deeply incised, jointed Featherbed Range.	Upper Permian.	Younger than Pf^b and possibly Pf^c Co-magmatic with Pgz^b?	Strongly porphyritic.
PALAEOZOIC	,,		b) Pale-weathered, commonly flow-banded flows, pyeroclastics, felsites, some ignimbrites. Some localized flaggy sandstone with layers of coaly shale.	Generally forms the periphery of the Featherbed Range; forms the Tennyson Ring Dyke. Main outcrop area east of Koorboora.	Horizontal or low-dipping flows; thick dykes (e.g., Tennyson Ring Dyke).	Upper Permian.	Overlain by Pf^a younger than Pga, Pgz^c, S-Dm, and probably Pf^c. Intruded by coarse quartz-feldspar porphyry.	Spheroidal structures in some flows.
	,,		c) Dark-grey, green, or nearly black rhyolitic to dacitic ignimbrites, flows and pyroclastics.	Eastern portions of Chillagoe and Almaden 1-mile Sheet areas.	Near-horizontal expanses, massif structure, hilly topography.	Upper Permian. Possibly identical with Pf^a.	Overlying S-Dm, D-Ch. Intruded by Pgz-type granite, and by pink, rhyolitic dykes.	Strongly porphyritic Pf^a and Pf^c are possibly one and the same.
	Almaden Granite Pga	—	Biotite-bearing hornblende adamellite and granodiorite, grey.	Most of the granitoid rocks in the area between Almaden and the Walsh River.	Generally flat country, with scattered tors and outcrops.	Upper Permian.	Intrudes S-Dh, S-Dm, Pzur; is older than Pgz, possibly younger than ?Pga. Traversed by rhyolitic dykes. Overlain by Pf, but intruding Pun.	Possibly originated by assimilation of limestone by Herbert River Granite intruding Chillagoe Formation. Copper-lead-zinc-silver-gold mineralization.
	? Pga	—	Pyroxene-biotite-hornblende quartz diorite and gabbro, with hypersthene-bearing varieties.	Main exposures around Petford; south-west of Koorboora; and 12 miles south-west of Mungana.	Red-brown soil plain at Koorboora; elsewhere nondescript to hilly.	Upper Permian, possibly a more basic variety of Pga.	Older than Pf^b.	
	Herbert River Granite Pgh.	—	Grey to pale-pink hornblende-biotite adamellite, medium-grained.	Most of the granites south and south-west of Almaden; also represented in Almaden-Walsh River area.	Generally flat country; locally as jointed, hilly areas of exposure.	Upper Permian.	Intrudes Pgz^b near Khartoum. Transitional into Pga. Intrudes S-Dh, S-Dm, Ad.	
	Boxwood Volcanics Po.	Few hundred feet.	Grey to dark-green, porphyritic, rhyolitic and rhyodacite flows, pyroclasts. and ignimbrites.	Area west and south-west of Boxwood, south of Tennyson Ring Dyke, Almaden Sheet area.	Hilly country. Part of Boxwood Ring Complex.	Upper Permian.	Older than Pf^b, younger than Cr. Traversed by coarse quartz-feldspar porphyry.	
	Doolon Creek Rhyodacite Pd.	?	Grey or greenish, porphyritic rhyodacite.	Area along Walsh River at junction with Doolan Creek, Mungana Sheet.	Part of Doolan Creek Ring Complex. Low country.	Upper Permian? Possibly correlated with Pzur.	Older than Pf and Pgz^b, possibly also Pga.	
	Nychum Volcanics Pun.	Few hundred feet.	Grey ignimbrites and pyroclastics, basal agglomerate.	Outcrops along northern edge of Mungana Sheet area.	Low hilly country.	Upper Permian. Plant fossils in type area north of Walsh River.	Older than Pf; overlies Ad, S-Dh.	
	Undifferentiated. Pzur.	?	Grey, pink, or dark porphyritic micro-adamellite.	Localised area east of Redcap. Mungana Sheet area.	Hilly ranges up to 500 feet.	(Upper) Permian?	Intruded by Pga. Faulted boundary with S-Dh.	Either volcanic or sub-volcanic.
	Ringrose Formation Cr?	Few hundred feet.	Sericitic quartz sandstone and quartz siltstone, conglomerate.	North-east of Koorboora; and within area of Boxwood Ring Complex.	Hilly ranges. Bedding obscure. Dips moderate.	Probably Carboniferous, possibly equivalent with Ringrose Formation.	Seems to overlie S-Dm unconformably. Is older than Pf and Po, and older than Pgz.	Molasse-type deposit? Some pneumatalytic alteration. Host rocks for tin, wolfram deposits.
	Hodgkinson Formation D-Ch.	At least 20,000-30,000 feet.	Greywackes and feldspathic sandstones, micaceous siltstone, shale; subordinate chert, conglomerate, and breccia.	North-east corner of Chillagoe Sheet area; south-east corner of Almaden Sheet area.	Hilly ranges with north-north western trend. Dendritic drainage folded.	Middle Devonian to Upper Devonian, possibly Lower Carboniferous. Poorly preserved plant fossils, common.	Unconformably overlain by ?Pf; intruded by Pgh and Pgz. Faulted boundary with S-Dm.	Sandy-flysch facies of Tasman Geosynclinal zone. Deposition commonly by turbitity currents.
	Mount Garnet Formation S-Dm.	?	Quartz greywacke and siltstone with some chert, conglomerate, sedimentary breccias.	Areas between Redcap and Walsh River; between Almaden and Featherbed Range; around Koorboora; and south-south-east of Petford.	Nondescript; low rubbly ridges and hills, Structure; steeply folded.	Pene-contemporaneous with part of Chillagoe Formation, and partly overlying the latter. Age probably Lower Devonian in Chillagoe District.	In Chillagoe district, overlying the Chillagoe Formn. Faulted boundary against Hodgkinson Formn. Intruded by all granites, overlain by all Permian volcanics.	Clastic shelf association of Chillagoe shelf area. Host rocks for some deposits of tin, wolfram, lead-silver.
	Chillagoe Formation S-Dh.	Est. at roughly 5,000-10,000 feet.	Fossiliferous, massive limestone, bedded chert; quartz greywacke and siltstone; lenses of conglomerate, sedimentary breccia, and basic lavas. Basal member of sericitic quartz sandstone and siltstone.	Zone, 6 miles wide, from near Almaden north-west to Walsh R. and beyond. Enclave at Ootann between Almaden and Tate River.	Characteristic rugged limestone bluffs; low ridges of chert, conglomerate, and arenites; broad plains over siltstone and part of the limestone. Steeply folded.	Pene-contemporaneous in part with Mt. Garnet Formn., but normally underlying the latter in the Chillagoe district. Fossils: corals (e.g. *Halysites, Favosites* spp., *Cyathophyllum* spp.) crinoids, brachiopods, gastropods, Upper Silurian-Lower Devonian.	Overlain by Mount Garnet Formation; separated from Dargalong Metamorphics by Palmerville Fault; intruded by Almaden Granite, Herbert R. Granite, and Elizabeth Ck. Granite. Overlain by the Permian Volcanics.	Mixed shelf association of the Chillagoe shelf area. Host rocks for most of the copper, silver, lead, zinc deposits.
PRECAMBRIAN	Dargalong Metamorphics Ad	?	Mica schist, quartz schist, gneiss, augengneiss, granulite, migmatite, muscovite granite, amphibolite, pegmatite.	Occupies the greater part of the Mungana 1-mile Sheet area.	Low, mature landscape, gradually roughening towards the south. Steeply folded for the most part.	Age probably Precambrian, possibly Archaean.	Unconformably overlain by Wrotham Park Sandstone and Nychum Volcanics; faulted against the Chillagoe Formn., intruded by all Permian granites and dykes.	Host rocks for some copper, gold, fluorspar deposits and mica prospects. Metamorphosed probably in the garnet-amphibolite facies.

'Granulite' is a term used here to imply a metamorphic rock built up predominantly of equidimensional mineral grains, whose texture is attributed to metamorphism, not to first consolidation. In other words, 'granulite', as used here, has no connexion with the granulite facies of metamorphism. Some of the granulites strongly resemble muscovite granite, and it is conceivable that the muscovite granite in the Dargalong Metamorphics is the ultimate product of granitization (metasomatism), and is not magmatic granite: its contacts are ill-defined and gradational. The largest outcrop area, with at least a fairly well defined photo-interpreted boundary, is at Dargalong. A thin section of a sample from this area consists of quartz, untwinned potash feldspar, oligoclase, muscovite, and partly chloritized biotite, in order of decreasing abundance. The feldspars are partly sericitized and kaolinized.

Where the metamorphics are conspicuously interveined and interlayered with quartzo-feldspathic material, either by injection (Fig. 3) or by metamorphic differentiation, the term 'migmatite' may be employed (Pl. 2, fig.1). Augen gneiss (Pl. 2, fig. 2) is commonly found in such migmatized areas. A 'basic front' rim of biotite forms a margin around some quartzo-feldspathic veins.

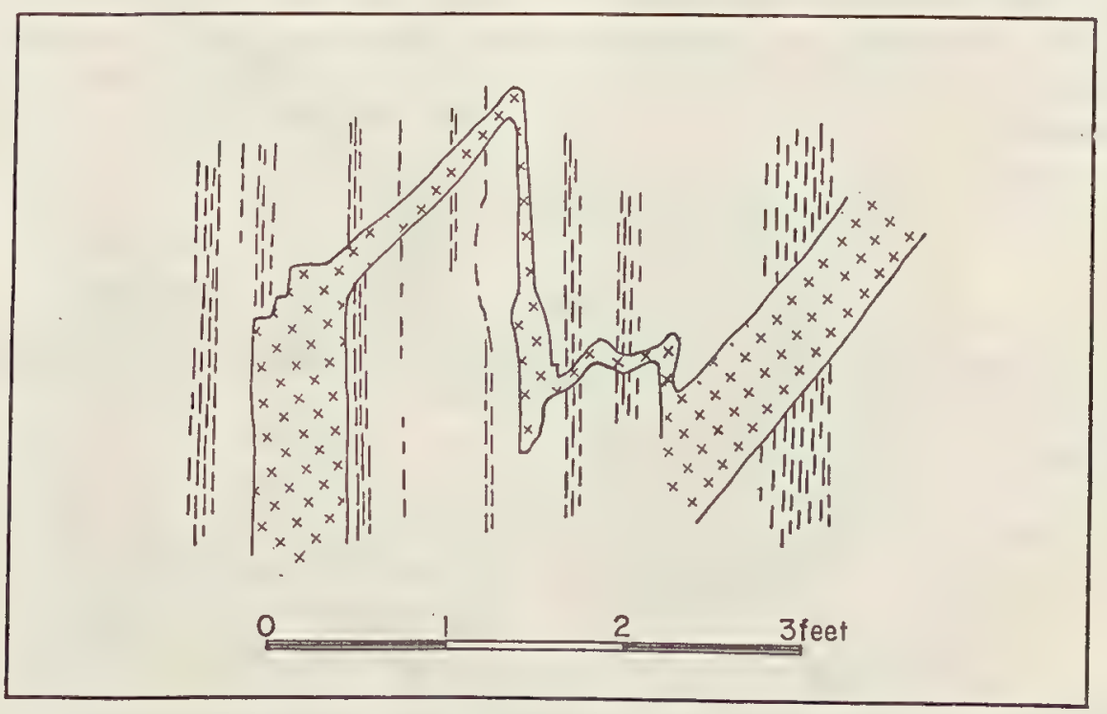


Fig. 3. Conformity and unconformity shown by a quartzo-feldspathic tongue in paragneiss, Wandoo Creek.

Quartz-feldspar-muscovite pegmatites are abundant in many areas, especially where granitic and granulitic rocks predominate. The veins are generally parallel to the foliation, but cross-cutting relationships are fairly common. The grain size is commonly of the order of several inches, and books of muscovite up to a foot across are known from the Mount Kitchin mica prospects (page 117).

The amphibolite is a dark green fine-grained to medium-grained rock composed of hornblende and plagioclase, together with some garnet, and is widespread

in the eastern part of the outcrop area; it seems to be absent in the western part. The amphibolite forms uniform sheets intercalated with the schist and gneiss, and occurs also as irregular masses. The irregular shapes of some outcrops and the fact that the amphibolite nowhere grades into other rock types may point to an igneous origin.

The Dargalong Metamorphics were probably derived from aluminous and siliceous sediments, fairly rich in potassium, which were metamorphosed and granitized, presumably at medium to great depth.

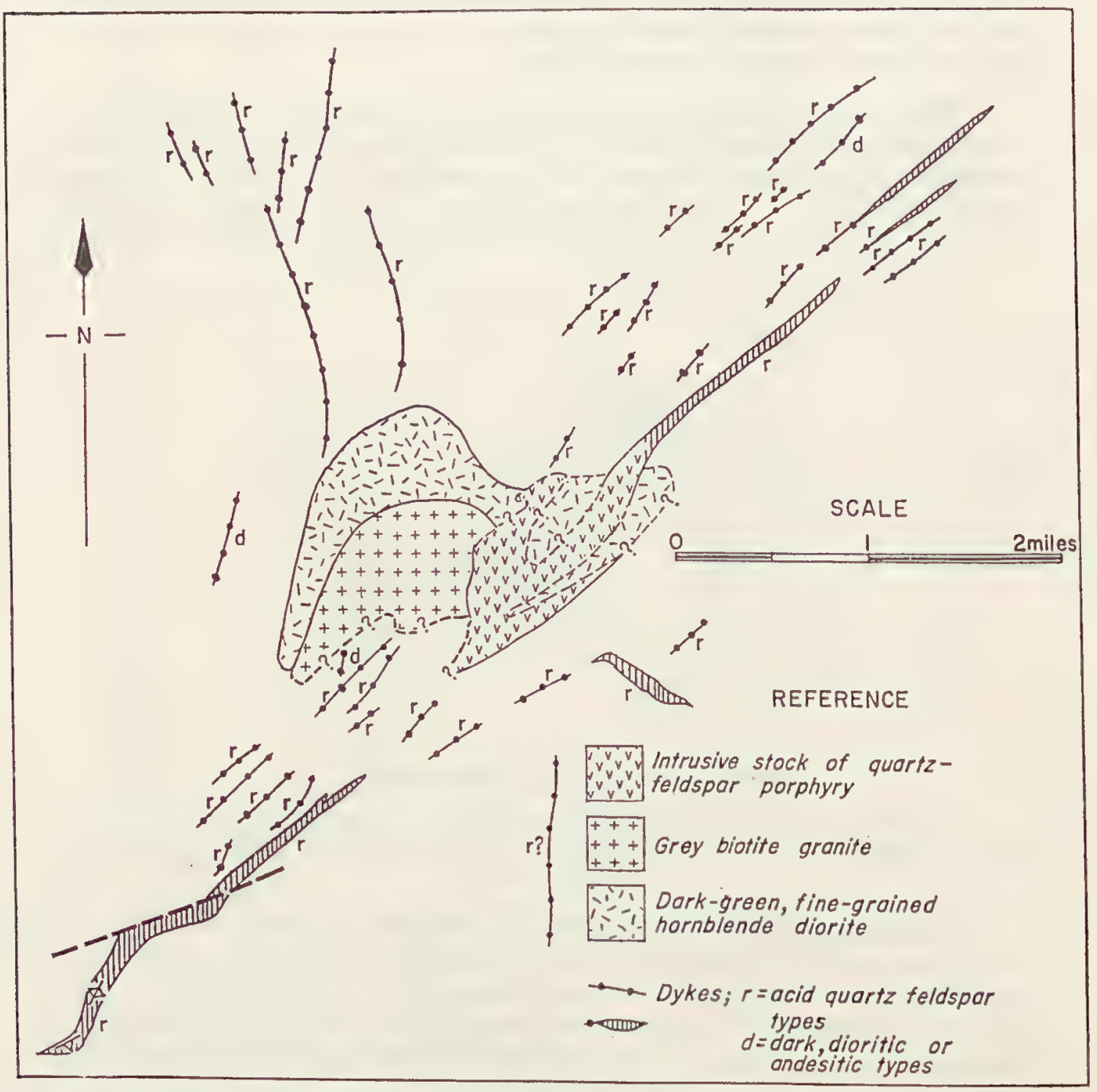


Fig. 4. Probable eroded sub-volcanic stock with dyke swarm. Mungana Sheet, 30 miles west of Chillagoe.

Metamorphism and Metasomatism

The grade of metamorphism cannot be determined with certainty, and more than one facies may be represented. Two thin sections of gneiss from outcrops on Muldiva Creek show the following, not very diagnostic, mineral composition: quartz, oligoclase, muscovite, and (chloritized) biotite. Specimens of amphibolite and gneiss from localities about 50 miles north of the Walsh River, outside the area mapped, contain andesine-labradorite feldspar, greenish brown hornblende, and garnet, and can be placed in the garnet amphibolite facies. Notwithstanding lack of compositional evidence in the Mungana Sheet area, the appearance in outcrop (Pl. 2), the coarse texture of some gneisses, and the presence of migmatite, all point to a high-grade metamorphism of the Dargalong Metamorphics in the Chillagoe district. Albite, reported by Jensen (1941), could not be found in the few thin sections examined.

Metasomatic processes have apparently played an active role during metamorphism. The potash feldspar augen in the augen gneiss are thought to be a result of potassium metasomatism: the potash feldspar (orthoclase or untwinned (?)microcline) contains ragged patches and shreds of muscovite, chloritized biotite, and quartz, which are thought to be remnants of the original mineral assemblage. Even the muscovite-biotite granite may be the ultimate result of metasomatism and granitization, as the granite does not appear to have sharp intrusive boundaries, seems to grade into granulite and gneiss, is composed of the same minerals—quartz, feldspar, muscovite, and chloritized biotite—as are the gneisses, and, under the microscope, shows plagioclase partly replaced by potash feldspar and quartz.

The Dargalong Metamorphics have all undergone retrograde metamorphism, which is expressed mainly in the universal chloritization of biotite and the alteration of feldspars. The rocks have also been subjected to post-metamorphic stresses: muscovite and biotite flakes are bent and warped, quartz is granulated and shows strain shadows and cataclastic effects. It is conceivable that these effects as well as the retrograde metamorphism were imposed on the schists and gneisses during the Carboniferous orogeny that folded the Palaeozoic geosynclinal sediments farther east.

Age

Until recently, no age more precise than pre-Silurian could be ascribed to the Dargalong Metamorphics. D. A. White (1961) considered them to be Precambrian, possibly Archaean, because of the apparent high grade of metamorphism. Certainly the inclusion of high-grade gneiss and amphibolite as pebbles in non-metamorphic Silurian conglomerate is conclusive evidence that a very long period of metamorphism, uplift, and erosion must have preceded the Upper Silurian sedimentation.

A granite sample taken from the vicinity of the Dargalong mines, on the Chillagoe-Bolwarra road, was dated at 1044 million years by the K/Ar method

in the Geochronology Laboratory of the Australian National University (see page 43). This indicates that the Dargalong Metamorphics are at least not younger than the Middle Proterozoic.

Post-metamorphic Intrusions

The Dargalong Metamorphics are intruded by a variety of igneous rocks, both acid and basic, in the form of dykes and dyke swarms as well as plutonic stocks.

Most of the plutons are adamellites and granodiorites, which are undoubtedly part of the Permian Herbert River Granite and Almaden Granite. Other intrusives are grouped on the map as undifferentiated rocks, where correlation with these granites is uncertain. They include stocks of muscovite-biotite granite, grey biotite granite, coarse pink biotite granite, and dark green hornblende diorite. One complex body of diorite and granite with associated dyke swarm, some 10 miles south-south-west of Cardross, possibly represents a deeply eroded volcanic or sub-volcanic system (Fig. 4).

The Dargalong Metamorphics are traversed by innumerable dykes of quartz-feldspar porphyry, felsite, and andesite or dolerite. They are probably contemporaneous with the Upper Permian dykes and volcanics in the Chillagoe and Almaden Sheet areas, and may represent feeder channels for volcanic deposits now removed by erosion. On air photographs the acid dykes stand out as thin white lines and ribs, whereas the basic dykes are shown as dark lines and grooves. Networks and swarms of dykes are particularly well expressed on air photographs of the areas 10 miles south-south-west of Cardross and 14 miles south-south-east of Cardross.

Boundary with the Palaeozoic

The Chillagoe Formation, which bounds the Dargalong Metamorphics in the east, contains conglomerate lenses with pebbles of gneiss and amphibolite, and a long period of erosion undoubtedly separates the two formations. However, the character of the actual boundary has long been a problem. Jack (1891), for instance, found the boundary in the Chillagoe district transitional and intergrading, whereas Ball (1918) found it abrupt; Jensen (1941) regarded the boundary as a fault, whereas Broadhurst (1952) saw only a normal, unconformable relationship.

In 1960, during the regional mapping of the Mossman 1:250,000 Sheet area which adjoins the Chillagoe district in the north, enough evidence was found to prove that the boundary is a large fault of regional proportions (the Palmerville Fault), trending from the western coastline of Princess Charlotte Bay in the north of Almaden in the south; from there to the south-east the fault is obscured by the masses of igneous rocks, but it can be picked up again as a strong lineament from the Herbert River Gorge to the Pacific coast at Halifax

Part of Mungana 1-mile Sheet, between Rookwood Station and Walsh River. (Stereopair). Six formations and igneous units are represented. Note characteristic development of limestone bluffs, roughness of Featherbed Volcanics (Pf), renewed incision of the Walsh River and its branches.

Fig. 1. Migmatite, Dargalong Metamorphics, Muldiva Creek.

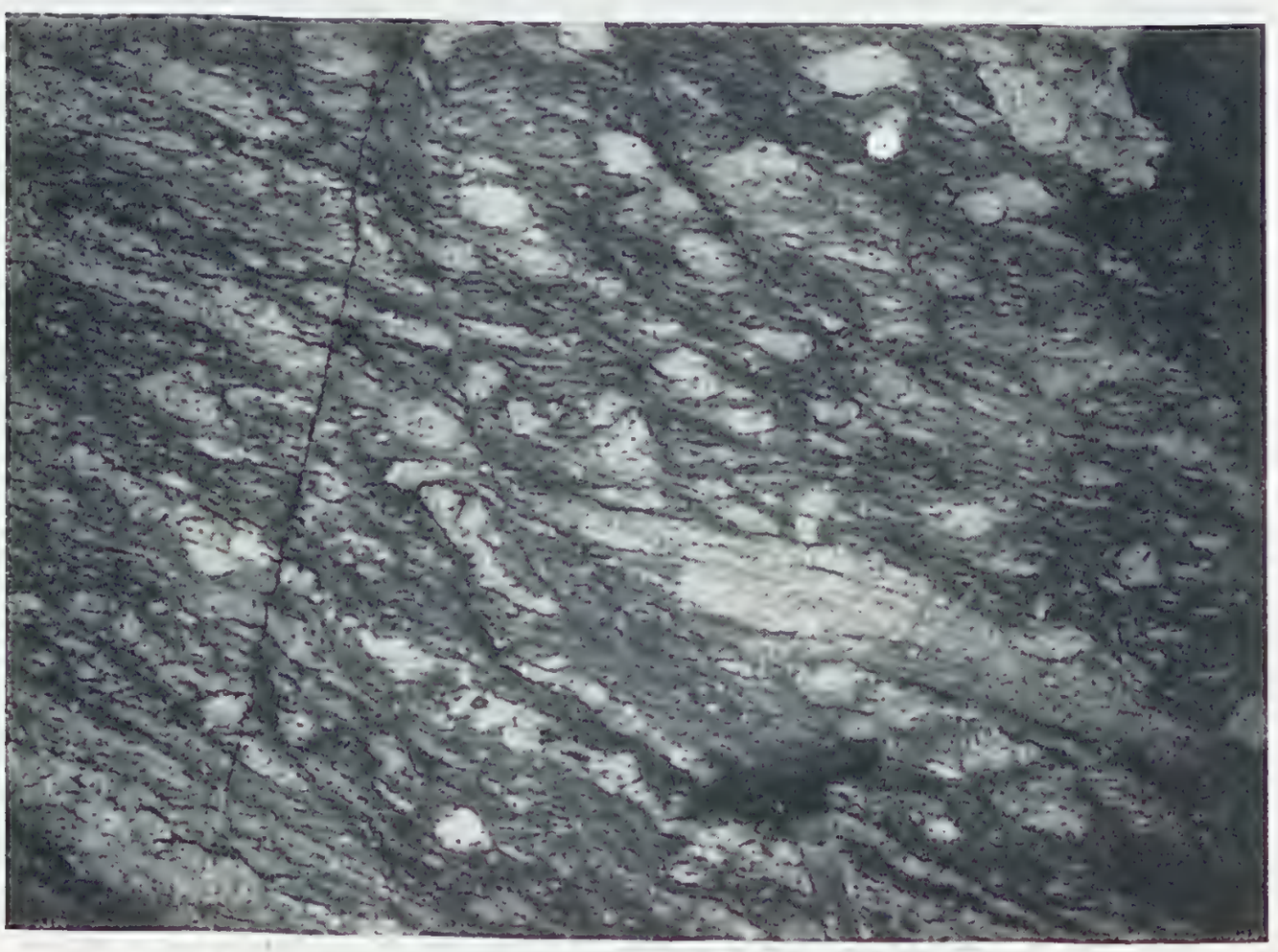


Fig. 2. Augen-gneiss, Dargalong Metamorphics, Muldiva Creek.

Fig. 1. Limestone bluff at Chillagoe, showing karren erosion.

Fig. 2. Stalactites in limestone cave, Chillagoe.

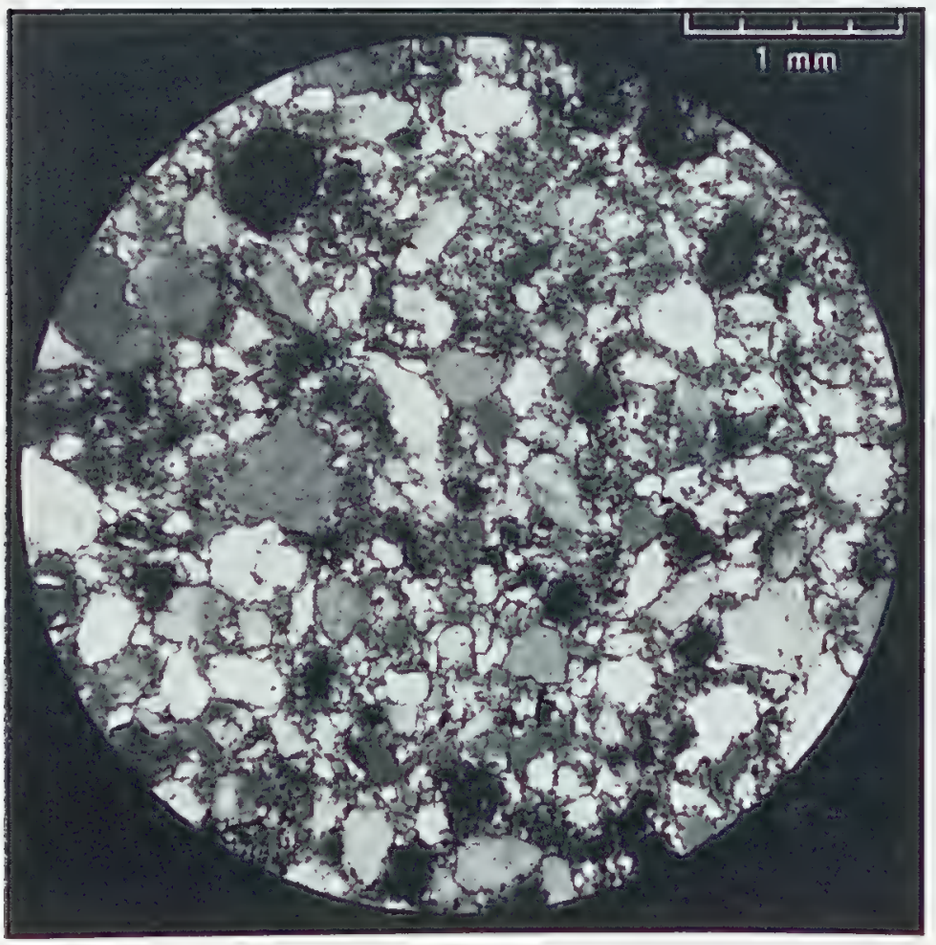


Fig. 1. Quartz sandstone, base of Chillagoe Formation. Mainly quartz, some chert, interstitial sericite.

Fig. 2. Spilite (?), Chillagoe Formation. Near roadside, half-way between Chillagoe and Almaden. A = albite, py = pyroxene (augite), ch = chlorite.

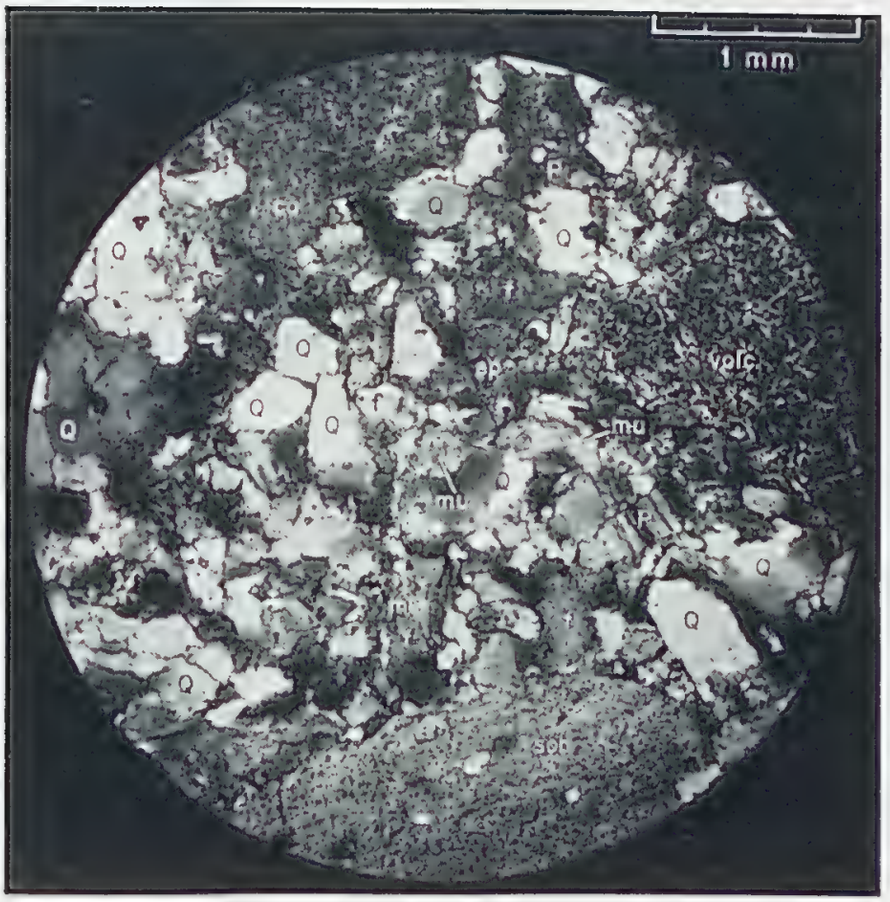


Fig. 1. Conglomeratic greywacke, Chillagoe Formation, Walsh River. Volc = volcanic, Q = quartz, P = plagioclase, sch = schist, f = altered feldspar, ca = calcite, mu = muscovite, ep = epidote.

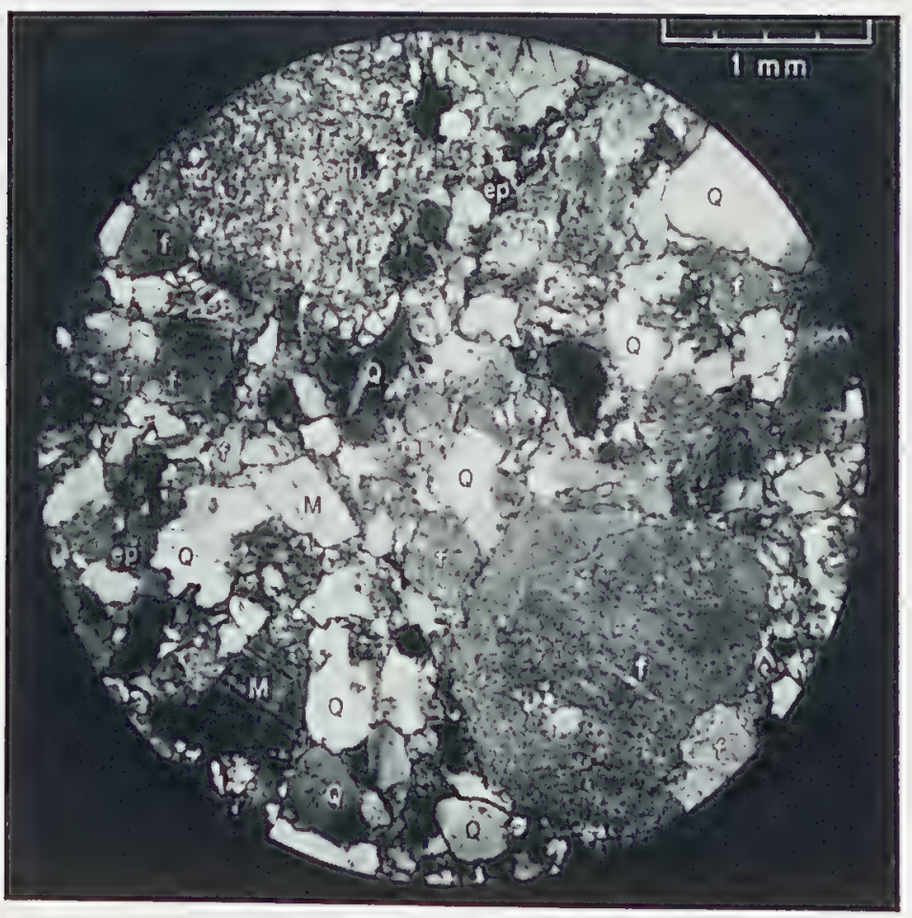


Fig. 2. Conglomeratic greywacke, Chillagoe Formation, Walsh River. Q = quartz, sch = quartz schist, M = microcline, mu = muscovite, O = orthoclase, A = albite.

Bay, south of Ingham. The coast-line along Halifax Bay to Townsville and beyond runs along the projected continuation of the fault, which must be considered to have been a major controlling factor in the formation of the coastal structure in this part of North Queensland (de Keyser, 1963).

The following evidence indicates the faulted nature of the boundary:

a. its absolute straightness and sharpness;

b. the absolute separation between the two formations—no outcrops of Dargalong Metamorphics exist east of the boundary, nor are sediments of the Palaeozoic formations found on the western side;

c. the movement or tilting of Cretaceous strata along the boundary;

d. a striking difference in topography on either side of the boundary, due to recent movements along the fault;

e. a graben formed as a wedge along the fault north of the Palmer River; in this graben down-faulted and crumpled Permian sediments have been preserved; the sides of the graben are part of the Palmerville Fault system;

f. physical effects on rocks of the Chillagoe Formation, which can be seen near Palmerville: along the boundary, sericitic schists occur that are probably the result of dynamo-metamorphism, and chert beds have been broken up;

g. the apparent control, in the area immediately north of the Walsh River, of the extent and distribution of the Permian Nychum Volcanics: outcrops of these volcanics are rare immediately east of the boundary, where they apparently have been removed by erosion;

h. the distinctive lithology of the base of the Chillagoe Formation: it is a distinctive fine-grained quartz sandstone and siltstone which is not repeated elsewhere in the formation, but is restricted to a zone adjacent to the fault, and probably genetically connected with it (see page 18).

The evidence proves conclusively the nature of the boundary; nevertheless, in the Chillagoe district it is not readily recognized. Here the fault-line is in many places marked by a peculiar massive green rock which under the microscope is seen to be composed of (?) dolomite with albite, calcite, chlorite, and quartz, in order of decreasing abundance. This rock is seen to alternate at one place with quartzite of the (?) Chillagoe Formation, and at another with mica schist. In places the green rock crops out in a zone hundreds of feet wide. As the rock is found nowhere else in either the Chillagoe Formation or the Dargalong Metamorphics, its origin must be sought in alteration processes connected with the faulting.

Where 'intergrading' seems to be present, the explanation must be sought in imbrication and the fading out of strong metamorphic contrasts owing to phyllonitization on the one hand, and retrograde metamorphism on the other.

Palaeozoic

Chillagoe Formation

The Chillagoe Formation occupies a north-westerly belt from the vicinity of Almaden to the Walsh River and beyond. An enclave is preserved in the granite near Ootann, south of Almaden. The western limit of the formation is the Ralmerville Fault; in the east the sediments are overlain by the Mount Garnet Formation (the boundary of which is arbitrary only), or are truncated by granite, which also forms the boundary to the south. The maximum width of the formation exposed in the area mapped is about 6 miles.

The formation was first named by Jack (Jack & Etheridge, 1892), who used the term 'Chillagoe Beds.' Skertchly (1899) described the 'Chillagoe Limestone' as overlying the clastic sediments in the area. Dunstan (1916) used the 'Chillagoe Series' to include the limestone as well as associated cherts and clastic sediments. The type area is the Chillagoe-Mungana district.

The Chillagoe Formation consists predominantly of chert and fossiliferous limestone, with intercalated quartz greywacke and siltstone, and subordinate conglomerate, basic volcanics, sedimentary breccias, and possibly acid volcanics. The base of the formation is formed by a series of fine-grained sericitic quartz sandstones and siltstones with a total thickness of 500 to 1000 feet in the area mapped, and containing small lenses of quartz conglomerate, quartz greywacke, basic lava, shale, and limestone. The fine-grained sandstone (Pl. 4, fig. 1) is pinkish yellow to grey or greenish, and is distinguished from all other members of the Chillagoe Formation by its characteristic appearance. In places it grades into chert or quartz greywacke. The fact that the sandstone occurs exclusively along the Palmerville Fault, from near Chillagoe to beyond Palmerville, and is not repeated anywhere else away from the fault, suggests that its formation is linked with the history of the fault. B. J. Amos (Bureau of Mineral Resources) pointed out, in a personal communication, that the sandstone is most probably essentially a diachronous litho-stratigraphic unit, which accumulated over a long period as the basin sank, aided by periodically recurring vertical adjustments along the fault. Resulting rapid lensing-out away from the fault and interfingering with the normal Chillagoe sediments would then explain the absence of any repetition of the unit, notwithstanding the heavy folding.

The best-known lithological units of the Chillagoe Formation are its fossiliferous limestone and chert, which are interbedded in roughly equal quantities. The limestone is massive, generally dark grey where fresh, and usually compact. Around granite intrusions the limestone is mostly bleached to a coarse light grey or white marble. Some of the darker limestone has a strong fetid smell when broken with a hammer. A few outcrops of a sugary, friable white limestone ((?)carbonate sandstone) are known.

Outcrops are commonly in conspicuous jagged bluffs, about 100 to 300 feet high, showing karren erosion and containing many caves (Pl. 3). This habit

is in strong contrast to the smooth, rubble-covered chert ridges, though low-lying smoothly worn limestone pavements are also exposed in several broad valleys.

On air photographs the bluffs are highly characteristic and unmistakeable (Pl. 1). Bedding is usually absent or hardly perceptible; thus it could happen that Skertchly (1899), in the belief that the limestone was essentially horizontal, arrived at the conclusion that it lay 'as a much denuded cake' unconformably over the cherts and clastic sediments of the Chillagoe Formation. However, careful examination during the 1958 season left no doubt that most of the limestone is nearly vertical, and is intercalated with the clastic sediments and cherts. Tight folding observable in rare thin-bedded limestone members also argues against the limestones' being remnants of a horizontal cover.

Some of the limestone contains chert lenses and tongues that swell laterally into branching layers of chert. Intensive interfingering of limestone and black chert is fairly common. Sandy limestone and calcirudite with arenitic matrix are also found in a few localities, mingled with lenses of limestone and chert.

Fossils are common, and are locally abundant in the limestone, but their preservation is not very good (list on page 21). A few fossils occur in chert. The fauna includes corals, which indicate a reef environment, but the outlines of the present-day bluffs do not necessarily coincide with original reef boundaries, and in some beds there is ample evidence for origin by mechanical deposition rather than by organic construction.

A striking feature of the limestone sequence is the occurrence of a rock here called 'breccia-conglomerate'. The fragments in it are either limestone or chert, and, rarely, reach diameters of several feet; fragments of other rock types, such as granite and gneiss of the Dargalong Metamorphics, were found in only a few places. Broadhurst (1952) regarded the breccia-conglomerates as volcanic breccias formed in diatremes; however, it is seen that the breccias form basal beds above local unconformities, and their long thin lateral extent in places, their occasionally sandy matrix, and the lack of recognizable volcanic rocks attest against the diatreme concept. The rocks are most probably sedimentary wave-platform breccias, locally contaminated with allochthonous pebbles and boulders.

The chert forms smooth, rounded rubble-covered ridges intercalated with the limestone and the clastic sediments. It generally shows regular rhombohedral joints, and its colour ranges from light grey to black, and from creamy through yellow to pink and red. The chert is commonly regularly bedded; the beds are from 1 to 3 inches thick and are separated from each other by shaly partings. Broadhurst (1952) distinguishes two classes—massive and bedded—but the distinction seems difficult to maintain because a unit which appears thinly-bedded in a creek exposure commonly seems massive where exposed on a ridge; the massive character of the lumps of rubble on the ridges is possibly attributable to their being derived from the thicker beds that are occasionally found in the thin-bedded cherts. Besides forming independent ridges, the chert also inter-

fingers with the limestone, narrowing from massive bodies to nodular bands and branching tongues. In places it also includes limestone lenses, and commonly weathers in the same manner as limestone. Some of the chert, particularly the dark grey variety, contains silicified fossils, including *Heliolites* sp., and, in one place, remnants of a sponge with well-preserved inner structure. The origin of some of the brecciated chert members is discussed on page 23. Some 'cherts' appear to be fine-grained calc-silicate rocks and basalts. A greenish chert from the Cambourne lode, Redcap area, proved to be a fine-grained altered basalt, and Jensen (1923) described diopside 'chert' from the Muldiva open cut and scapolite-zoisite-diopside 'chert' from the Zillmanton road.

Shale and siltstone are readily eroded and therefore poorly preserved, so that outcrops are small and inconspicuous; but these rocks are thought to underlie a considerable proportion of the area covered by soil. Green and brown weathered varieties are common, and a black siliceous variety also occurs. Where fresh, most siltstones are grey or bluish-grey. Where they are more massive than shaly, the siltstone and mudstone may be conspicuously cross-bedded. Sequences of regularly alternating dark siltstone and fine-grained pepper-coloured sandstone usually show graded bedding, fine-scale cross-lamination, and scour-and-fill structures. It was noted that on the hillsides the siltstones tend to be more indurated than their counterparts in the creek beds.

The arenaceous members—quartz greywacke[1], pebbly quartz greywacke, feldspathic sandstone—vary in textural and mineralogical maturity. Some are coarse and poorly sorted, contain much feldspar and many rock fragments, and locally grade into fine conglomerate; a few are more even-grained. Under the microscope the quartz greywackes and pebbly arenites are seen to be composed of quartz, feldspar, muscovite, chert, and fragments of limestone, schist, basalt, porphyry, quartzite, and other rocks (Pl. 5, fig. 1).

The conglomerate members are coarse and polymict, and occur as bands and lenses, particularly in the lower (western) portion of the succession. Boulders and pebbles are well-rounded and include chert, amphibolite, muscovite granite, gneiss, and other rock types with diameters ranging from gravel size up to a general maximum of 10 inches, set in quartz greywacke or sandstone. Larger boulders are known—one measured two feet by one foot.

Finally, there are some basic and probably some acid volcanics in the succession. The acid types are porphyries closely resembling the Permian pohphyries, but they were steeply tilted in the outcrop investigated (along the road north of Rookwood station), and, if they are not in-faulted wedges of Per-

1) Throughout this report the terms 'greywacke' and 'quartz greywacke' are used to imply sediments texturally and mineralogically immature, with moderate to poor sorting and rounding, large amounts of muscovite, feldspars, and rock fragments, and various amounts of a sericitic and quartzose, or, more rarely, a clayey matrix. Quartz greywackes contain a higher proportion of quartz and generally a more siliceous matrix; greywackes are richer in feldspars, mica, and rock fragments.

mian intrusives, must be intercalated in the Chillagoe Formation. Also, rhyolite has been found as fragments in a pebbly quartz greywacke. However, no outcrops of undoubtedly intercalated acid volcanics were found.

Basaltic (or andesitic) lavas are common, and indeed are one of the main components of the Chillagoe Formation some 60 miles north of the area mapped, in the region north of the Palmer River. Some of the outcrops may represent later dykes and sills, but the extrusive nature of other exposures is indicated by the presence of pebbles of this basic rock in a stratigraphically higher conglomerate. Some basaltic members are probably spilitic; a specimen of an outcrop about half-way between Almaden and Chillagoe is composed essentially of albite, augite, ilmenite, and chlorite, arranged in a pilotaxitic texture. However, the augite does not show the alteration characteristic of this mineral in spilites; it is, in fact, remarkably fresh (Pl. 4, fig. 2).

Palaeontology and Age

Fossils are almost entirely confined to the limestone, in which they are locally very abundant and commonly segregated in layers. Their preservation is usually not good; species determination is difficult because of silicification. Types identified or recorded are:

Corals: 1. Tabulata—*Favosites, Heliolites, Halysites, Cladopora, Propora.* (Identification by Prof. D. Hill and others.)

2. Rugosa — *Tryplasma, Kyphophyllum, ?Fasciphyllum* (identification by Prof. D. Hill);
Spongophyllum, e.g., S. cyathophylloides, Cyathophyllum, e.g., *C. dunstani, C. chillagoensis,* (Etheridge, 1911);
Cystiphyllum (Jensen, 1941);
Xystriphyllum, Pseudamplexus, Grypophyllum (Bryan & Jones, 1945).
The corals are the most abundant of all fossils in the area.

Crinoids: Very abundant, and in places forming crinoid limestone.

Brachiopods: Less common than crinoids, except in local concentrations. No specimens as yet determined. In places a big, stout-shelled variety 8cm. across occurs, probably *Stringocephalus* (identification Prof. D. Hill).

Gastropods: Rare. Species found were high-coned.

A few fossils were found to occur in chert. These include:

Radiolaria: reported by CSIRO (1950a).

Corals: *Heliolites* sp. (a few highly silicified fragments).

Sponges: A representative of the Demospongea, probably of the sub-order Eutaxicladina. This single example appears to be spheroidal, and is internally well preserved; elsewhere rare spicules are tentatively identified.

The fossil assemblage has Silurian affinities (*Halysites*), but the possibility that sedimentation has extended into Lower Devonian times is not excluded, as suggested by finds of doubtful *Stringocephalus* from two miles east of Rookwood (White & Hughes, 1957) associated with a pelecypod species also found in the Clarke River area (outside the area mapped), where a Middle Devonian age has been diagnosed.

The age of the Chillagoe Formation is here tentatively given as Upper Silurian, possibly extending into the Lower Devonian.

Origin of Some of the Types of Sediment

The origin of some of the sediments in the Chillagoe Formation is a matter of dispute. Jensen (1941) believes, for example, that the chert is silicified calcareous shale, whereas Broadhurst (1952) regards it as silicified tuff. The latter idea is based on the microscopic identification of partly or completely replaced feldspar crystals (CSIRO, 1950a); however, feldspar can also be an authigenic mineral, or may have been produced by metamorphism by the granite. One would also expect, in a tuff, other fragments such as quartz, possible hornblende, glass shards and the like. Another obstacle is the presence of fossils in the centre of the chert beds, so that the chert is not likely to represent a suddenly deposited tuff-layer suffocating the fossils 'just above coral reefs' (Broadhurst, op. cit.). The cherts are believed to be most probably either silicified calcareous oozes or primary precipitates or silica. If they are primary, the bifurcation and the rhythmic banding in the chert beds may, as Broadhurst has suggested, be attributed to diagenetic differentiation in accordance with Davis' theory.

A number of conglomerates and breccias, especially in the Redcap and Mungana areas, have been interpreted by Broadhurst as volcanic breccias; but a different origin is here proposed. The limestone breccia-conglomerate, for example, is here regarded as a wave-platform breccia overlying local unconformities and disconformities. An unconformable relationship could also be explained by the presence of diatremes, but several other factors make the volcanic hypothesis improbable; for example, the absence of any undoubted volcanic material, and the great lateral extent of some thin breccia-conglomerate sheets, and the fact that it is almost exclusively limestone that is brecciated in this fashion. For, whereas volcanic diatremes would be unlikely to be selective, limestone reefs would logically have been built up in some of the shallowest parts of the Chillagoe shelf and would therefore have been highly susceptible to destruction during even slight lowerings of sea-level.

The chert breccias of the Redcap and Girofla pipes both occur in limestone. Broadhurst (1952) has regarded the pipes as diatremes filled with silicified tuffs. This suggestion was based on the presence of partly or wholly replaced feldspar in the chert. However, as feldspars may have other modes of origin, and truly volcanic fragments have not been found (a pyroxenite from a drill core at Redcap may well be a calc-silicate rock rather than an igneous one), the evidence is

scanty. Furthermore, as McKinstry (1955) points out, pipes are rather common in limestones, and this circumstance in itself is an argument against a general theory involving volcanic pipes. Finally, there can be seen at Redcap pairs of fragments whose matching profiles show only negligible movement since fracturing: this is more compatible with brecciation in situ than with volcanic activity. Jensen (1941) thought that the Redcap and Girofla breccias were chiefly due to faulting, but there is no sign of milling or preferred orientation. Nor is the breccia sedimentary, because there is no sign of bedding, rounding, sandy matrix, or sheet-like deposition.

Two processes that may have been responsible for the brecciation remain to be considered: a. brecciation brought about by the collapse of a rock into a cavity left by a solution of a limestone or oxidation of an ore; b. brecciation caused by hydrothermal-pneumatolytic corrosion. The hypothesis of a collapse breccia does not explain why the 'filling' of the pipe should in every place be chert, but hydrothermal brecciation seems to explain all observed facts in the least complicated way: the occurrences in limestone because of the weakness of limestones against chemical attack; the filling with chert, which may represent hydrothermally silicified limestone; the lack of rounding and—in places—displacement of the fragments; and the mineralization in the Redcap and Mungana Breccias.

Finally, some of the normal conglomerates, e.g., the conglomerate lens west of the Morrison mine in the Redcap area, were also regarded as volcanic breccias by Broadhurst (1952). The rounding of the pebbles and the occurrence of sandy lenses (occasionally with cross-bedding) or a sandy matrix are generally sufficient evidence for their sedimentary origin. Also, the conglomerate lens at the Morrisson mine and the chert breccia at Mount Redcap are within a mile of each other, and it seems unlikely that, if both rocks were volcanic, the rock should be exclusively chert in the one, and be composed mainly of Dargalong Metamorphics in the other.

Depositional Environment

All evidence suggests a near-shore, shallow-water, mixed clastic and reef environment with frequent oscillations of sea-level, a rapid shifting of facies, and entry of clastic material from the west. The evidence is:

a. the fauna of corals and sponges. Recent siliceous sponges rarely live at depths greater than 225 feet; colony-forming corals have an even shallower lower limit—about 150 feet.

b. the local unconformities and disconformities, wash-outs, scour-and-fill structures, and small-scale current-bedding.

c. the rapid interfingering and intergrading of chert and limestone, chert and siltstone, limestone and sandstone, sandstone and siltstone, etc.

d. the well-defined (but small) lenses and tongues of coarse, well-rounded conglomerate containing pebbles and boulders of Dargalong Metamorphics.

e. some sediment sequences, for example, the thin-bedded alternating siltstone/pepper-sandstone sequence with its associated scour-and-fill, graded bedding, and other features, strongly resemble photographic illustrations of recent littoral sediments such as are deposited in tidal channels (Straaten, van, 1959).

The general absence of a markedly coarse basal sequence might suggest that the clastic sediments were derived from a low-lying, morphologically mature or old continent.

Mount Garnet Formation

Sediments in three separate areas — Redcap, Koorboora, and Petford to Emuford — were, after the 1958 field season, included in the 'Herberton Beds' (Skertchly, 1899) by de Keyser, Bayly, & Wolff (1959), but should probably be correlated with the Mount Garnet Formation (Best, 1962); use of the term 'Herberton Beds' is no longer warranted, as the mapping of the Atherton 1:250,000 Sheet area has shown (Best, op. cit.).

The boundary between the Chillagoe and Mount Garnet Formations is ill-defined and arbitrary, and is drawn where the limestones have largely disappeared (and the cherts are becoming scarcer). As discussed later (page 25), the Mount Garnet Formation is probably partly penecontemporaneous with, and partly younger than, the Chillagoe Formation. The top of the Mount Garnet Formation is not represented in the Chillagoe district because it is hidden by the overlying Featherbed Volcanics, or is a faulted boundary like that in the area south of Petford.

The Mount Garnet Formation consists of quartz greywacke, greywacke, quartzite, sericitic siltstone, and shale, with subordinate intercalations of chert, conglomerate, and sedimentary breccia, and an occasional lens of limestone.

In the Koorboora and Petford-Emuford areas, chloritic siltstone and shale are also common, and the ratio of greywacke to quartz greywacke seems higher. A thick and extensive conglomerate member is found six to nine miles south-south-east of Petford; it contains well-rounded pebbles of quartz, quartzite, and other sediments, including rocks probably belonging to the Dargalong Metamorphics. Between Koorboora and Torpey's Crooked Creek mine, dark grey soft graphitic schists are intercalated.

In general, the composition and texture of the sediments are much the same as those of the clastic members of the Chillagoe Formation, with which no sharp boundary exists. Bedding characteristics vary; the most well-bedded members are those composed of alternating layers of dark siltstone and pepper-coloured sandstone, commonly showing cross-lamination, slump-structures, and graded bedding. The thickness of these layers is generally between half an inch and two inches. Of the coarser arenites, some are massive and structureless, and show no sign of bedding, whereas in other exposures regular thin beds are prevalent.

Throughout the succession, massive and well-bedded members alternate, and quartz greywacke also occurs as lenses in siltstone.

The massive quartz greywacke is composed of quartz, feldspar, muscovite, chert, and fragments of several other rocks (Pl. 5, fig. 2). Some of the greywacke has a calcareous matrix. Quartz greywacke grades—without sharp boundaries—into fine uneven-grained conglomerate in which pebbles are of quartz, chert, siltstone, etc. The conglomerate also has many cavities, in a few of which relics of dissolved limestone fragments can be found. Besides the conglomeratic and pebbly greywacke varieties, the greywacke also includes lenses of fairly pure quartz sandstone.

Weathering of the greywacke commonly leads to spheroidal structures, and the rocks may then superficially resemble igneous rocks: Jensen (1941), for instance, confessed that he had trouble distinguishing them from 'syenite'.

The chloritic shales, which are especially abundant in the Koorboora area and south of Petford, were considered by Skertchly (1897) to be altered basic dykes, but this suggestion cannot be upheld. They are commonly associated with tin lodes and may be shale and siltstone that were chloritized by widespread hydrothermal processes.

The few chert lenses present are identical with the chert of the Chillagoe Formation.

Broadly speaking, the Mount Garnet Formation may be defined as a Chillagoe Formation without chert and limestone, and it is probably partly penecontemporaneous with, partly younger than, the Chillagoe Formation. Within the Chillagoe district the Mount Garnet Formation is undoubtedly younger, but beyond the boundaries of the area mapped, near Mount Garnet, the Chillagoe Formation as such has largely disappeared and has been replaced by the Mount Garnet facies. Near the Mitchell River, north of the area mapped, on the other hand, the Mount Garnet Formation is absent, and the Chillagoe facies, which is there well-developed, is in direct contact with the Hodgkinson Formation.

It is conceivable that the Chillagoe Formation represents a mixed-type shelf facies as described by Kuendig (1959); the Mount Garnet Formation may be designated as its clastic-type shelf counterpart, possibly deposited in a deltaic-lagoonal environment. It is not necessary to consider the Mount Garnet Formation as an off-shore, deeper-water equivalent of the Chillagoe shelf association; the lithology of the clastic Chillagoe members is virtually identical with that of the Mount Garnet sediments. It is probably more a question of hinterland relief: where there was strong erosion in the source area supply of clastic material was plentiful, and coral reefs were not likely to flourish: a Mount Garnet facies resulted. Where, on the other hand, the hinterland was flat and mature, supply of clastics became scarcer and more localized and coral reefs more abundant: a Chillagoe facies was deposited. This reasoning seems in line with the assumption of tectonic land in the south, as White has proposed (1961).

Though no fossils were found, the age of the Mount Garnet Formation probably ranges from Upper Silurian to Lower Devonian by analogy with the Chillagoe Formation.

Hodgkinson Formation

The north-eastern corner of the Chillagoe Sheet area and the south-eastern edge of the Almaden Sheet area are occupied by sediments of the Hodgkinson Formation ('Hodgkinson Beds' of Jack, 1884). They are, like the older Palaeozoic formations, steeply folded and tilted, and consist of micaceous greywacke, siltstone, and shale, interbedded in a broadly uniform and monotonous series containing sporadic intercalations of chert and conglomerate. Small lenses of limestone and flows of basic volcanics are known from areas just beyond the boundaries of the Chillagoe Sheet.

The lower boundary of the Hodgkinson Formation is concealed in the Chillagoe district by the overlying Permian volcanics. About seven miles south-south-east of Petford, sediments of the Hodgkinson Formation are separated from probable members of the Mount Garnet Formation by an inferred system of faults. The upper boundary is unknown, but the formation is unconformably overlain by essentially horizontal (?)Permian volcanics in places north-west of Wolfram Camp.

The greywacke ranges from coarse to fine-grained, and grades into siltstone. It has typical immature mineralogical composition and texture, the particles poorly sorted and subangular; the amount of matrix (averaging an estimated 10 per-cent) is commonly below the usual percentage implied by the term 'greywacke'. The structure is generally massive, although the finer members are commonly well-bedded at about 1-foot intervals. Graded bedding, slumping, and some cross-lamination in places allow the determination of top and bottom relationships and show that overturning is fairly common.

With slight variations in matrix content and relative abundance of mineral species, the greywacke grades into quartz greywacke and feldspathic sandstone.

Where fresh, the greywacke is dark bluish or greenish-grey, but it becomes yellow brown, olive green, or purplish-grey on weathering. Pebbly and gritty lenses and tongues are present throughout the exposed sequence. The shale is soft, smooth, and fissile, and is generally grey or greenish-grey and probably chloritic, though black shale also occurs. In volume the shale is subordinate to the greywacke and siltstone, and forms only thin intercalations.

Palaeontology and Age

Remains of plant fossils are widespread, but in the Chillagoe district consist only of poorly preserved stem fragments. From the type area in the Hodgkinson Gold Field, north-east of the Chillagoe district, Jack (1884) reported the occurrence of *Lepidodendron* (?) *australe,* and of *Retzia* sp. and *Cyathophyllum*

helianthoides from a penecontemporaneous limestone conglomerate. Jack & Etheridge (1892) described *Pachypora* sp. and *Cyathophyllum* sp. from the limestone. *Favosites* sp., *Grypophyllum* sp., and other corals were identified by Prof. D. Hill (personal communications). Mary E. White (1960, 1961) described the occurrence of *Leptophloeum australe* (McCoy) and possible Psilophyte stems.

The evidence thus indicates a Devonian age. During the 1961 field season Bureau of Mineral Resources geologists in the Cooktown area collected corals from a limestone lens in the Hodgkinson Formation; they were examined by Prof. Hill, who ascribed to them a 'probable late Lower Middle Devonian or an early Middle Middle Devonian age' (pers. comm.). Concrete evidence for an age extending into the Lower Carboniferous, which is commonly assumed, has not been found thus far.

Deposition of the Hodgkinson Formation must have started at latest in the Middle Devonian and in all likelihood continued into the Upper Devonian, and possibly—though this is without proof—into the Lower Carboniferous.

Depositional Environment

De Keyser et al. (1959) thought that the greywacke and siltstone of the Hodgkinson Formation were deposited in a 'basin-type' delta environment (Dapples, 1947). The idea is, perhaps, justifiable for the small part of the formation exposed in the Chillagoe district, but work outside this area, in particular by K. G. Lucas (Bureau of Mineral Resources), has shown that in general the Hodgkinson Formation is a geosynclinal trough deposit with a flysch facies, partly laid down by turbidity currents (de Keyser, 1961). Typical of such a flysch facies are, according to Termier (in Oulianoff, 1960), the following features: essentially detrital character; more or less regular alternation of arenites and micaceous shales, with occasional intercalations of conglomerate and lenses of limestone; a thickness of many thousands of feet of rather monotonous, undifferentiated lithologies in which fossils are few and sub-division virtually impossible. In the Swiss Alps (Trumpy, 1960), the flysch sandstones are micaceous and feldspathic, show poor sorting and rounding, and have a silty cement, whereas 'typical' greywacke (in the original sense) is rather uncommon. The shales are silty and sandy and generally micaceous.

All the above-mentioned features are characteristic of the Hodgkinson Formation. Even negative features are recognisable: Trumpy's (op. cit., p. 891) description: 'Flysch cordilleras have a disconcerting tendency to vanish into thin air, thus the . . . granite which furnished great boulders to the Wildflysch is not known in outcrop'; is exactly analogous to the situation in the Hodgkinson Basin in general.

The depth of deposition of flysch sediments is rather variable, and there is, according to the latest research, a repeated and irregular shifting of axes of subsidence and uplift.

In the area north of Wolfram Camp, massive arenites are predominant, turbidity features are not common, and rare limestone lenses are associated with sedimentary limestone breccias in which a corallogene fauna points to shallow-water conditions; this part of the Hodgkinson Basin was probably not far removed from its source land, whose coastline probably ran in a general north-westerly direction somewhere through the Chillagoe district.

Ringrose Formation (?)

On the southern side of the Tennyson Ring Dyke, within the Boxwood ring complex structure, and in an area one to two miles north of Koorboora, there occurs a series of sericitic quartz siltstone and fine-grained quartz sandstone which may have a Carboniferous age.

Their lithology is quite distinct from that of the Mount Garnet Formation, in which they seem to occur. Their colour is white or pale grey or greenish, commonly spotted with purple or red iron stains; in thin section all are seen to be quartz-sericite rocks with interstitial sericite, chlorite, and accessory biotite, tourmaline, apatite, sphene, zircon, and (?)rutile (Pl. 6, fig. 1); there is some evidence of pneumatolytic alteration in the form of sericitization (quartz corroded by sericite) and the growth of rare tourmaline clusters. Some thin sections carry both euhedral and corroded quartz grains and shadowy relics of large feldspar crystals, and it seems very likely that part of the quartz 'siltstone', at least, may be pneumatolytically altered tuff or other volcanics. The sediments are rather structureless, and attitudes are not easily recognizable, but, where observed, dips were only moderately steep.

De Keyser et al. (1959) originally included these rocks in the Mount Garnet Formation ('Herberton Beds'), although they noticed the difference in lithology. K. G. Lucas, more familiar with the stratigraphy of the Herberton district, suggested after a short visit to the outcrops north of Koorboora that the beds might be Carboniferous (personal communication). In 1961 de Keyser visited both the Herberton and the Chillagoe districts and found further evidence for a possible Carboniferous age: the beds commonly dip less steeply than the Mount Garnet sediments, and they crop out only within the Boxwood ring complex and the Featherbed cauldron structure. In other words, the quartz siltstones may unconformably overlie the Mount Garnet Formation; and their restriction to the specific areas mentioned above means that only in these down-faulted blocks were they protected against complete removal by erosion, thus implying that they were in a higher stratigraphical position than the Mount Garnet sediments.

As the sediments show some affinity with the (?)Carboniferous Ringrose Formation near Herberton, they are here tentatively correlated with that unit.

The relationship with the Boxwood Volcanics is not beyond doubt. M. B. Bayly, one of the geologists of the 1958 survey, thought that they were interbedded with the volcanics, but this seems improbable: in places the contact

between the volcanics and the (?)Ringrose Formation closely follows the hill contours, although the quartz siltstone is moderately steeply tilted. The impression is gained that the volcanics formed sub-horizontal flows or sheets around the base of a hill which was the eroded remnant of a (?)Carboniferous land surface. In one locality there is a little peak composed of porphyry on top of a sandstone hill higher than the surrounding volcanics; this may be the eroded remnant of a volcanic neck protruding through the sandstone, in which case the volcanics are definitely younger than the Carboniferous sediments.

Permo-Carboniferous Igneous Rocks

The Palaeozoic geosynclinal sediments were folded and uplifted, probably during the Carboniferous, and were subsequently denuded to a region of low relief. Tectonic stresses were, after the uplift and erosion, relieved by tensional strain, leading to fissuring and cauldron subsidence with accompanying extrusion of large volumes of lava flows and ignimbrites, and the intrusions of granitic batholiths.

These Permo-Carboniferous igneous rocks are widely distributed over the areas covered by the Chillagoe and Almaden Sheets; outcrops in the Mungana Sheet area are less extensive. Some of the outstanding topographic features—the Featherbed Range in particular—are composed of Permian volcanics. The relationships between the various types of granite*, between the volcanic sequences, and between the granites and volcanics, have always been a problem to investigators, though the difficulties arise mainly from trying to fit all units into a single episode. The problem will be discussed in the relevant section on the volcanics and the granites.

The Permian volcanic deposits are only slightly folded and undulating, and they dip at angles generally less than 15 to 20 degrees. They overlie the older Palaeozoic formations with strong angular unconformity, and are partly intruded by some of the granites. They may be subdivided into five or more units on both geographical and stratigraphical grounds, some of these units are probably of approximately the same age, but geographical separation and the impossibility so far of accurately dating them makes attempts at correlation unwarranted. Some of the units (1, 2, and 5 below) are associated with ring complexes and cauldron subsidence blocks.

The five units are:

1. Boxwood Volcanics;
2. Doolan Creek Rhyodacite;
3. Nychum Volcanics;
4. The porphyries at Redcap;
5. Featherbed Volcanics (divisible into two or three sub-units).

*) In this publication the term 'granite', where used without qualification, denotes a variety of granitoid rocks, including granite, adamellite, granodiorite, granophyre, alaskite, leucogranite, monzonite, etc.

Boxwood Volcanics

The Boxwood Volcanics are associated with the Boxwood ring complex, which occurs in the Almaden Sheet area along Oaky Creek, west of Boxwood, and occupy about 45 square miles on the south side of the Tennyson Ring Dyke. The Boxwood Volcanics were made a separate unit by geologists of the Bureau of Mineral Resources after fieldwork during the years 1960 and 1961, and consist mainly of rhyodacite, which is generally grey and massive and strongly porphyritic.

The most common rock types contain abundant phenocrysts of plagioclase and quartz, 0.25 to 4 mm. across, in a dark grey aphanitic matrix. The plagioclase is twinned and zoned and has a composition ranging from oligoclase to andesine; albite is common in some members. Potash feldspar is less common as phenocrysts, occurs more generally in the matrix, and amounts to less than two-thirds of the total feldspar content. Biotite is the normal mafic constituent, and is usually bleached, partly chloritized, or altered to magnetite and epidote. Vestiges of altered hornblende remain in some thin sections. Accessories include sphene, apatite, magnetite, and allanite. The groundmass shows signs of being devitrified. Cracks and veinlets in the rock are filled with secondary alteration products such as epidote and chlorite. Inclusions of foreign rock types are fairly common, and include fragments of quartzite and chert, fine-grained pink leucocratic granite or aplite, and basaltic or andesitic rocks.

Most members are massive, structureless, and strongly porphyritic, but fine-grained felsitic varieties, fragmental (?) tuffaceous rocks, and flow-layered rocks were also noted. The angularity of mineral fragments, in some specimens, set in a devitrified groundmass, suggests that these members could be welded tuffs.

The Boxwood Volcanics form the higher parts at the northern, eastern, and southern rim of the Boxwood ring complex, and are most probably younger than the suspected Carboniferous sediments. The inclusions of granite or aplite indicate that they are also younger than at least part of the granites. A minimum thickness of 200 or 300 feet may be estimated.

Doolan Creek Rhyodacite

At the junction of Doolan Creek and the Walsh River, 10 miles north-north-west of Chillagoe, a second ring complex was found in 1961 (Fig. 5). Rhyodacite—for which the name Doolan Creek Rhyodacite has been proposed—forms the outer ring of the complex. The rhyodacite is massive, porphyritic, and generally green-grey where fresh, but turns red-brown on weathering. Phenocrysts of quartz and oligoclase, several millimetres across, are set in microcrystalline, xenomorphic, equigranular, and clear quartz-feldspar matrix which shows signs of having been recrystallized, an effect probably due to intrusion by granite. Mafic minerals—mainly biotite—have been largely altered to chlorite, epidote, and calcite. Some of the biotite forms clusters of fine scales, possibly in pseudo-

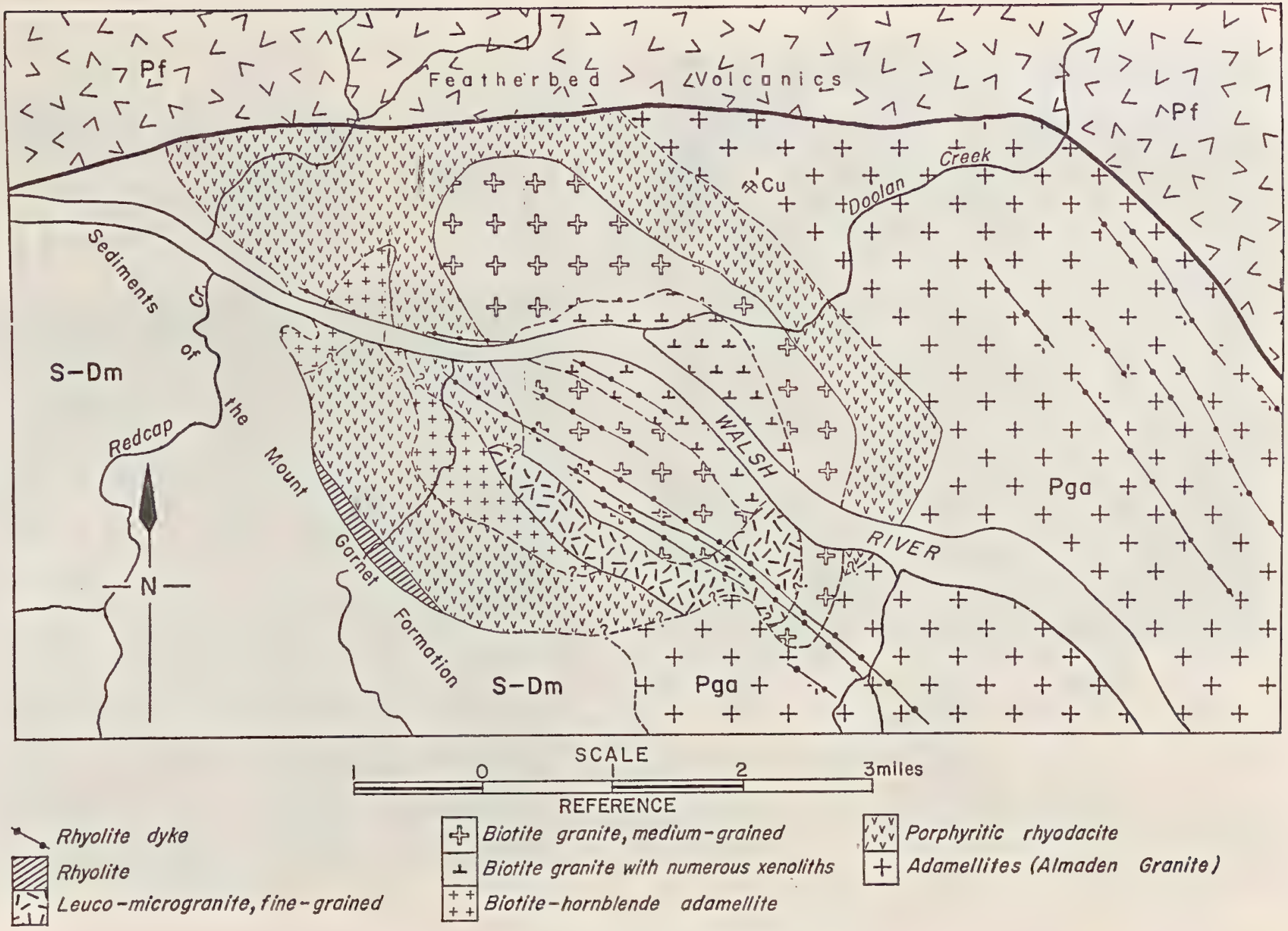


Fig. 5. The Doolan ring complex.

morphs after hornblende, and may be further evidence for recrystallization due to heat. Apatite and magnetite are accessory. Although potash feldspar was not seen as phenocrysts, it is virtually the only feldspar in the matrix (unless some of the clear feldspar is untwinned albite); thus the name 'rhyodacite' seems warranted.

The Doolan Creek Rhyodacite is probably effusive-volcanic, but definite evidence has not been found so far, and in view of its occurrence as part of a ring complex the unit may equally well be intrusive sub-volcanic. The thickness cannot be estimated, as the relief is extremely low and the base is not exposed.

On its northern side the complex is abruptly terminated against the Featherbed Volcanics by a large fault representing the rim of the cauldron subsidence area in which the Featherbed Volcanics were deposited.

Nychum Volcanics

The Nychum Volcanics were recognized as a separate unit during the 1960 field season in the Mossman 1:250,000 Sheet area north of the Walsh River (de Keyser, 1961), and were fully described by Morgan (1961). An outlier is exposed in the northern part of the Mungana Sheet area, along the Walsh River north-west of Rookwood Homestead, and consists here of massive, porphyritic rhyodacite and hornblende andesite with volcanic breccias and pyroclasts near the base. Their effusive character is recognizable north of the Walsh River, where several old vents or eroded volcanic necks have been found. In the type area a maximum thickness of 500 feet has been measured, and lateral variations in the flows and sheets are so common that no two fold sections are alike (Morgan, 1961). The Nychum Volcanics are terminated against the Featherbed Volcanics by a large fault, and are obviously older. Plant fossils from associated sediments in the type area suggest an Upper Permian (or perhaps even Lower Triassic) age, according to Mary E. White (1961), while the pollen and spore content has an Upper Permian affinity (B. E. Balme, pers. comm.).

Porphyry at Redcap

Near Redcap Mountain, massive porphyry covers an area of seven and a quarter square miles, three to five miles north-east of Mungana, forming hilly country rising several hundred feet above the surrounding area. The rock is a porphyritic micro-adamellite with a microscopic texture strongly resembling that of the Doolan Creek Rhyodacite. Phenocrysts, 0.5 to 3mm. across, of quartz and plagioclase are set in a grey, pink, or less commonly dark, aphanitic to microcrystalline groundmass with an average grain-size of less than 0.1 mm. This groundmass consists of an equigranular, xenomorphic mosaic of clear quartz and untwinned potash feldspar (and possibly untwinned albite), and shows signs of recrystallization under thermal conditions (Pl. 6, fig. 2) undoubtedly during the intrusion of the nearby Almaden Granite. Biotite, partly chloritized, is the main mafic mineral; iron oxide, epidote, and muscovite are accessory.

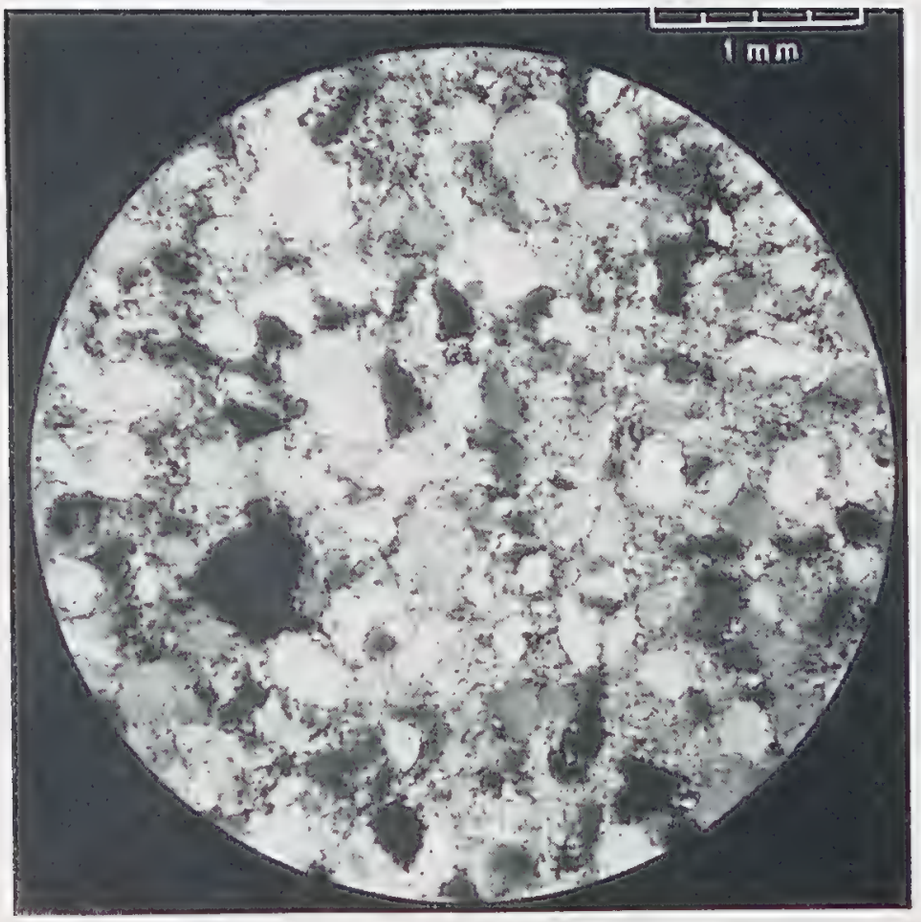


Fig. 1. Sericitic quartz sandstone, Boxwood Ring Complex. Quartz, with interstitial sericite; some pneumatolytic corrosion.

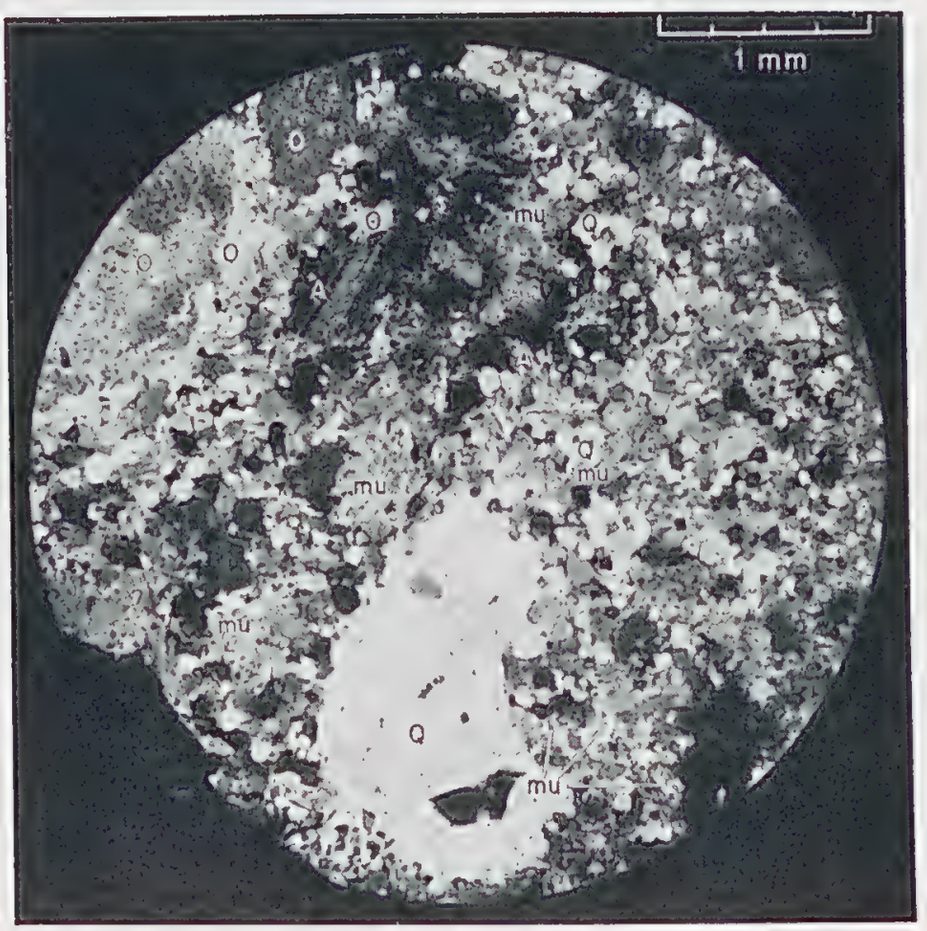
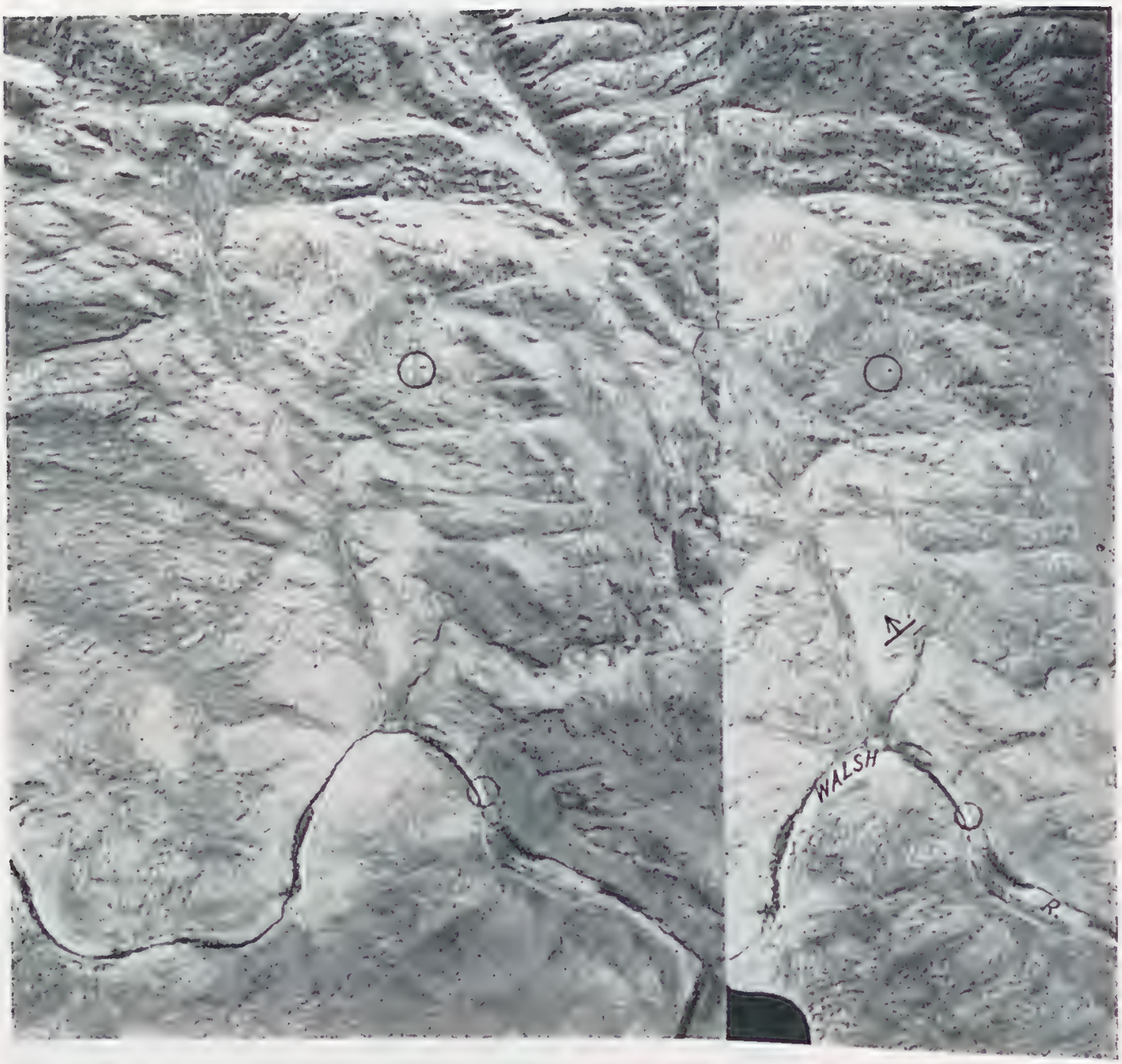


Fig. 2. Porphyrite-microadamellite, Redcap. Q = quartz, mu = muscovite, O = orthoclase, A = albite.



Part of the Featherbed Volcanics along the Walsh River, Chillagoe 1-mile Sheet (Stereopair). Note rough topography, scarcity of vegetation, intense jointing controlling drainage pattern, and obscure bedding.

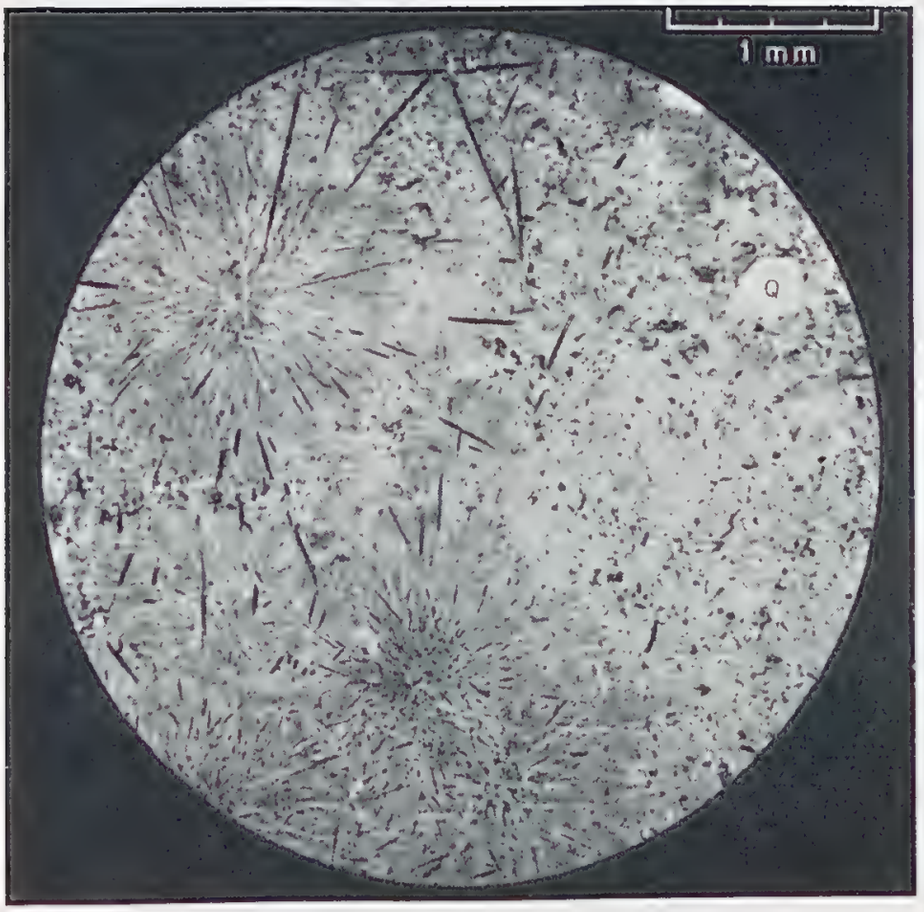


Fig. 1. Spherulitic rhyolite dyke, south-east of Almaden. Q = quartz

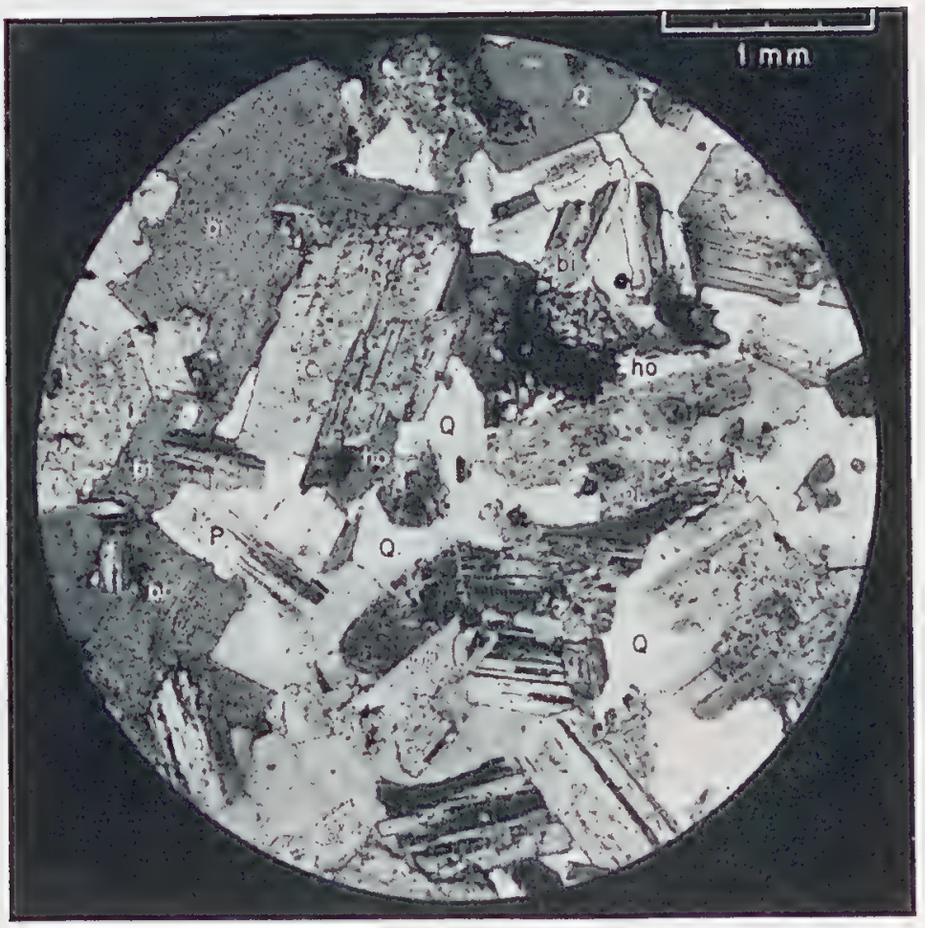


Fig. 2. Pyroxene-hornblende-biotite-quartz diorite, Petford. (Between crossed polarizers). P = plagioclase, Q = quartz, bi = biotite, ho = hornblende, py = pyroxene.

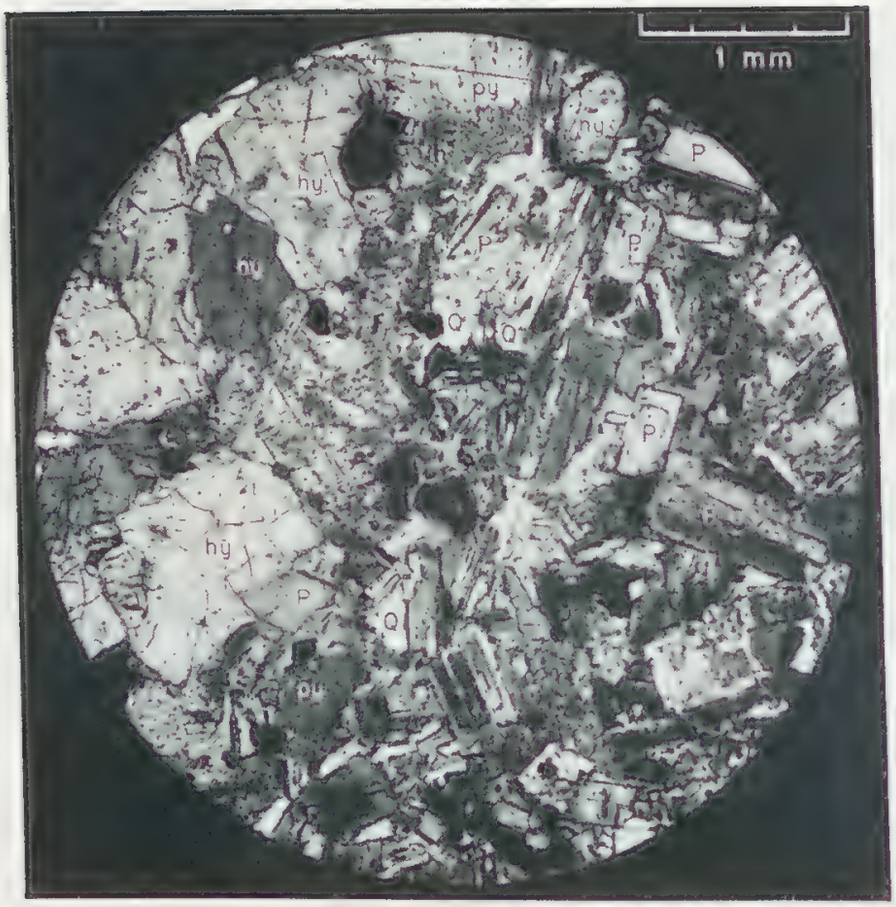


Fig. 1. Hypersthene-pyroxene-quartz diorite, 19 miles west-south-west of Chillagoe. (Between crossed polarizers). P = andesine, hy = hypersthene, py = pyroxene, Q = quartz.

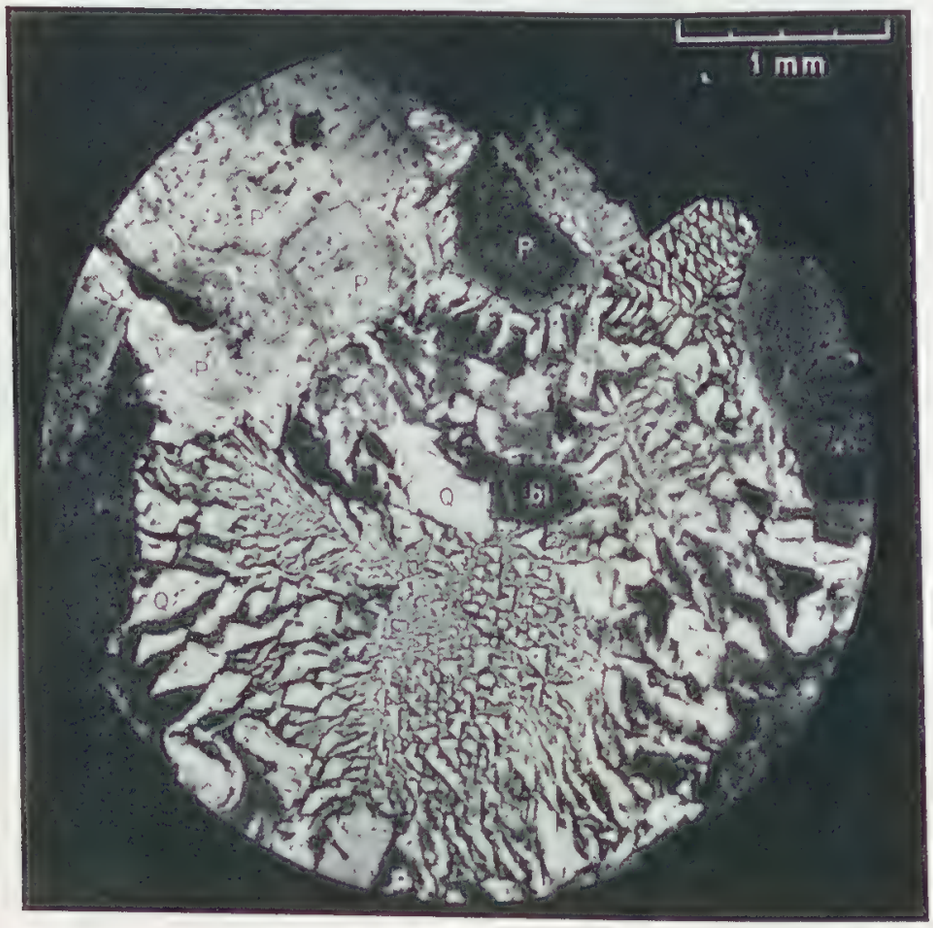


Fig. 2. Granophyre, Boxwood Ring Complex. P = plagioclase, Q = quartz, bi = biotite. Black: orthoclase in extinction position.

Broadhurst (1952) noticed associated scoria and tuffs, and consequently assumed an extrusive origin. Air photographs show a distinct rectilinear west-north-west zoning, characterized by different tonal values, and indicate a steep dip to the south. The widths of individual zones range from a quarter of a mile to three-quarters of a mile. This type of zoning is not characteristic of rocks that originated by flow over a land-surface, and the presence of muscovite and the relative coarseness of the groundmass in the thin sections examined would normally suggest that they were, in fact, not effusive rocks, if it were not for the possible explanation of these features provided by the presence of granite and the pneumatolytic alteration and thermal recrystallization that no doubt accompanied its intrusion. Perhaps the steep zoning represents originally horizontal bedding that became steeply tilted during faulting, and the porphyries would thus represent a thick wedge between the fault planes.

The porphyry at Redcap resembles the Doolan Creek Rhyodacite texturally, and may possibly be correlated with it.

Featherbed Volcanics

The Featherbed Volcanics, by far the most voluminous of the Permian volcanics discussed in this Bulletin and occupying most of the Chillagoe Sheet area and a large portion of the Almaden Sheet area, have built up the rugged Featherbed Range and form extrusive sheets over other parts of the district, east and north of Petford. They cover about 440 square miles in the Featherbed Range, within the boundaries of the mapped area, and a further 350 square miles in the adjoining Mossman 1:250,000 Sheet area, north of the Chillagoe district. The photo stereo-pair (Pl. 7) shows the typical photographical expression of the rock unit; although at first glance the massive rocks seem quite structureless, closer inspection reveals low bedding dips in places.

The total thickness of the Featherbed Volcanics, which consist of rhyolitic to rhyodacite flows and ignimbrites, must be at least 2000 feet, as the Walsh River has incised itself that much below the level of the higher summits without exposing any of the older formations.

After the 1958 survey, de Keyser et al. (1959) subdivided the Featherbed Volcanics into three superposed units (Fig. 6), for reasons to be discussed later (page 36). C. D. Branch (pers. comm.) is of the opinion that there are only two of these units, the top and 'bottom' ones being the same. The top and bottom units are certainly much alike; both comprise massive, generally dark grey, green-grey to black, acid to intermediate porphyry with a devitrified aphantic groundmass. The phenocrysts—quartz and feldspar—are closely spaced and commonly about 2mm. across. The rocks are structureless, and weather to boulders retaining their dark colours or turning to a deep red-brown. Viewed under the microscope they commonly appear to be ignimbrites.

The middle unit, on the other hand, is distinct from the other two: its members are usually weathered white, cream, pink, yellow, pale green, or pale

brown, though they may be black or grey when entirely fresh. Flow-banding and vesicular, amygdaloidal, or spheroidal structures are quite common. Weathering generally produces rocky rubble-masses instead of rounded boulders. Phenocrysts are less abundant, and may be wholly lacking in some varieties; the proportions of quartz and feldspars also vary widely. The groundmass is aphanitic and very dense. Agglomerates and volcanic breccias are widespread, particularly in basal sections, where they generally contain fragments of sediments and are likely to be bottom-flow breccias.

The spheroidal beds have a structure for which no easy explanation can be evoked. In the Tennyson Ring Dyke, spheroids range from ½ in. to 2 in. diameter, and are clustered like bubbles in contact; elsewhere, especially on the sides of the Walsh River gorge, spheroids are from 1in. to 3in. across and closely packed, but apparently not with impinging forms. Some spheroids have a porous core or irregular central cavity; in some, such a space is filled with opal, in others the whole spheroid is dense and flinty. A parallel to radial structure may be seen under the microscope. At the Walsh River locality, spheroids occur near the top of a certain flow.

Although most of the Featherbed Volcanics are massive and structureless, there is sufficient evidence to indicate that they are effusive rocks: low bedding dips can be recognized on air photographs; the attitude of columnar jointing, the occurrence of a thin horizontal chert-like rhyolitic layer sandwiched between massive members, and the presence of a fossil volcanic vent five miles north-east of Petford, all indicate their effusive origin.

Sedimentary intercalations in the Featherbed Volcanics are very rare and of limited extent. One locality is about three miles north-east of Koorboora and shows grey to cream, well-bedded flaggy sandstone (probably tuffaceous), and thin-bedded water-lain or reworked ashstone and tuff with graded bedding and alternating with fragmental rhyolite beds. It is here that impure coal is exposed (Q.G.M.J., 1910), which is interlaminated with tuff and ash. These sediments are at or near the base of the volcanic pile and dip at angles of about 5 degrees.

Dykes

In addition to the units described above, numerous acid and some basic dykes traverse the country. They normally contain small (1-3 mm.) phenocrysts, but there is also a very coarse variety of quartz-feldspar porphyry with phenocrysts of feldspar up to 2 cm. long.

The typical acid dyke weathers pink, brown-red, yellow, buff, grey-green, or white; fresh rock is generally grey. Phenocrysts of quartz and feldspar are embedded in a flinty, felsitic, or microcrystalline matrix. Occasionally the matrix carries spherulites consisting probably of albite (and (?)silica) (Pl. 8, fig. 1), presumably as a devitrification product. Kelyphytic rims on phenocrysts are

also developed in some places. Flow-banding is common, and shows the effects of drag along the walls; it also proves that the dykes are intrusive in the granite and do not represent undigested rafts of porphyry.

In the coarse variety of quartz-feldspar porphyry the groundmass is similar to that of the normal type, but the phenocrysts are much larger. The feldspar is white or pink, euhedral, zoned, and commonly altered at the core; the quartz is water-clear and may be euhedral, and the grains are mostly between 5 and 10 mm. across. In a few places the coarse dyke rock can be traced laterally into a dyke rock of normal appearance.

In places the dykes are grouped in swarms, e.g., south of Cardross (Fig. 4), and on both the west side and the east side of the Featherbed Range. They are probably the deeply eroded roots of volcanic feeder channels.

Basic dykes are known, but they are far less common than the acid dykes. They are also less common on the Chillagoe and Almaden Sheet area than they are on the Mungana Sheet area. Near Lappa Junction they intrude the granite.

Origin and Deposition of the Permian Volcanics

The Permian volcanics were deposited in ring structures and areas of cauldron subsidence as well as in normal surface flows. Associated sediments—flaggy sandstone, re-worked or water-laid tuff, impure coal—are strictly localized, and indicate by their fossil content and bedding structures (de Keyser, 1961) that the Permian landscape was one of low relief, with isolated shallow lakes scattered over its surface.

The Permian vulcanism was a result of the tensional strain that followed the Carboniferous orogeny. Fissures and normal faults were formed while granite was making its way upwards, and some of the fissures acted as feeder channels for the comagmatic and coeval volcanic products. Faulting, formation of ring structures, and finally cauldron subsidence accompanied these processes. The Tennyson Ring Dyke is a fine example of a composite ring dyke that has been only superficially eroded: spilled-over flows are still preserved west of Lappa Junction. This area is probably a shallow portion of the Featherbed cauldron subsidence area, and the Tennyson Ring Dyke may continue, unrecognized, around most of the edge of the Featherbed Range and form part of it.

Volcanic necks and vents are still preserved in places, e.g., five miles north-east of Petford and possibly at two or three localities in the Boxwood ring complex; many are probably still unrecognised. Some exposures seem to represent deeply eroded sub-volcanic roots and stocks: examples are the complex 30 miles west of Chillagoe, and possibly some of the granite porphyries on the eastern periphery of the Featherbed Range.

Although there are normal lava flows, tuffs, and pyroclasts among the volcanic products, most were undoubtedly deposited as ignimbrites or welded

tuffs—they occur in very thick units (sections of several hundred feet are commonplace) of non-bedded, structureless material, with great lateral extent and low angles of dip: the 'phenocrysts' are usually angular, and quartz phenocrysts are, in places, deeply embayed and corroded; the matrix is devitrified, and signs of welding are occasionally visible.

Age and Correlation

Because the volcanics are generally associated with, and localized at, fault-lined structures, the various units are difficult to correlate. Only for the Nychum Volcanics has an age been determined—from plant fossils and microflora (de Keyser, 1961); they are Upper Permian. In view of the great similarity of lithology and structural setting, all the volcanic units described above are included in the Upper Permian in this Bulletin. The Featherbed Volcanics are probably the youngest member, as their outer boundary fault cuts off any surrounding volcanics and structures that happen to be in contact with them.

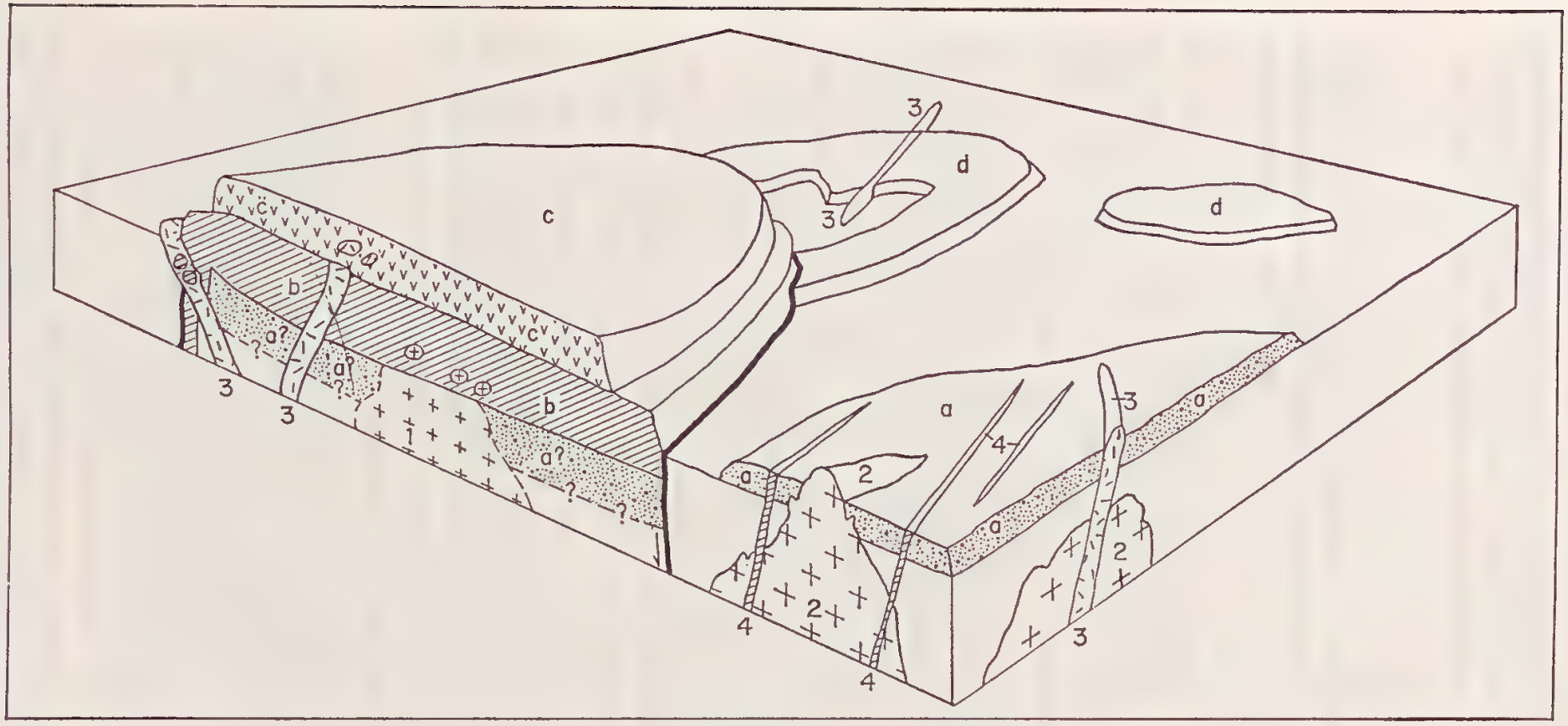
In Figure 6 the observed relationships between some of the volcanics and granites are brought together. A few deductions are shown in broken lines.

De Keyser et al. (1959) divided the Featherbed Volcanics into three subunits: a lower 'dark' prophyry ('a' in Fig. 6) indicated on the Chillagoe and Almaden Sheets as Pf? (Plates 11 and 12); a middle 'pale' porphyry (b), indicated on the maps as Pf; and an upper 'dark' porphyry (c) indicated also as Pf, but with a different pattern. The reasons for this subdivision may be seen on the diagram: porphyry (a) is intruded by granite, has undergone some mineralization (Dover Castle tin mine and lead prospects) and is traversed by dykes that are very probably a degenerated northern continuation of the Tennyson Ring Dyke (which belongs to the 'pale' porphyries (b)); porphyry (b) is overlain by the upper 'dark' porphyry (c), contains inclusions of granite, and is intruded by coarse quartz-feldspar porphyry dykes that do not intrude (c); which, however, contains inclusions of the dyke material.

C. D. Branch, on the other hand, thinks that the two 'dark' porphyries represent one and the same unit (personal communication), and ascribes differing relationships with the granite to the fact that granite intrusions have taken place at more than one time.

The Granites

Granitic rocks occupy most of the southern and western parts of the Almaden Sheet area and the western part of the Chillagoe Sheet area, and are also exposed east of the Featherbed Range and west of the Palmerville Fault. They form rather flat, sand-covered surfaces for the most part, with scattered boulder hills and tors cropping out in places; in some areas they have higher relief, and their massive joint-controlled lithology is then easily recognizable on the air photographs.



REFERENCE

Feathérbed Volcanics

- c — *Upper "dark" porphyry : massive grey-green ignimbrites*
- b — *Middle "pale" porphyry : pale-coloured, flow-banded flows, pyroclastics, ignimbrites*
- a — *Lower "dark" porphyry : massive grey and dark ignimbrites, flows, pyroclastics*

Other Volcanic Units

- d — *Ignimbrites, rhyodacite, etc. Boxwood, Doolan Creek, and Nychum Volcanics*
- 4 — *Acid porphyry dykes, possibly coeval with b*
- 3 — *Coarse quartz-feldspar porphyry*
- +2+ — *Biotite granite, greisen (Elizabeth Creek type ?)*
- + 1 + — *Coarse, leucocratic granite (Elizabeth Creek type, coarse variety ?)*

Fig. 6. Observed relationships between Permian volcanics and granite.

The granites intrude all pre-Permian formations and igneous rocks, and part of the Permian volcanics. Boundaries are sharp and well-defined, thermal metamorphism slight (except in the limestone areas), and the granites are clearly high-level intrusions. Branch (1961) has inferred that their depth of intrusion was about 1000 feet.

Marginal effects of the intrusions include auto-greisenization, induration, and generally slight metamorphism of the surrounding rocks. Although effects of a slight auto-pneumatolytic alteration—degeneration of biotite, sericitization of feldspars—are fairly widespread, strong greisenization is restricted to areas in the roof-zone of certain cupolas, as at Wolfram Camp, Bamford Hill, in the Emuford area, and probably also in the granite 14 miles west-south-west of Chillagoe. The granite here has been locally transformed into quartz-muscovite rocks with specific accessory minerals such as topaz, fluorite, tourmaline, etc. These greisen areas are of economic importance, as they are the loci for certain ore deposits—tungsten, molybdenum, bismuth, tin, and possibly rare metals.

Metamorphism of surrounding rocks is slight where the intruded sediments are siltstone and greywacke, and in such places takes the form of induration and silicification. In the limestone areas of the Chillagoe Formation, on the other hand, strong mineralogical changes were induced, leading to complete recrystallization of limestone, or to the formation of skarn rocks composed of garnet (grossularite-andradite), wollastonite, tremolite, actinolite, epidote-zoisite, diopside, scapolite, albite, and magnetite. Some of the most important copper-silver-lead ores of the Chillagoe district are associated with these contact rocks.

A minor economic product of limestone metamorphism may be the silica quarry at Chillagoe (page 118), which possibly represents an extreme case of silicification of limestone by granite.

The tough, dense, calc-silicate hornfelses that have been developed in layers of impure limestone resemble bands of chert in limestone, but can easily be distinguished from them under the microscope. Other dense calc-silicate rocks are hardly distinguishable, in outcrop, from fine-grained andesite or basalt; an example is the garnet-scapolite-calcite-hornblende-chlorite rock from near the road side about seven miles north-west of Almaden.

Metamorphism in the volcanics is less easy to see. Nevertheless, micro-study shows that near granite contacts some of the porphyries have phenocrysts with crenulated margins whose depth is related to the coarseness of the matrix, which is recrystallized to a clear, uniform quartz-potash feldspar mosaic with equidimensional grains (Redcap and Emuford areas) (Pl. 6, fig. 2). Moreover, feldspar phenocrysts are generally sericitized and clouded near a granite contact (Ball, 1919).

The granites, *sensu lato,* include a great variety of rock types, extending over granite, adamellite, granodiorite, alaskite, quartz diorite, and monzonite, and including such rocks as granophyre, microgranite, granite porphyry, and others

distinguished by differences in texture and grain-size. Biotite and hornblende, the chief mafic constituents, are present in various proportions, and some of the more basic rock varieties contain monoclinic pyroxene and hypersthene as well. The various granites grade into one another; sharp boundaries are rare.

De Keyser et al. (1959), after their field work in 1958, grouped all varieties together as belonging to one batholith with numerous modifications. However, Branch (1961), from his field work in areas outside the Chillagoe district, recognised two separate epochs of granite intrusion—an older one, giving rise to the Herbert River Granite, and a younger period during which the Elizabeth Creek granite was emplaced.*

The Herbert River Granite is normally a grey or very pale pink hornblende-biotite adamellite. The *Elizabeth Creek Granite* is characteristically a pink-red, leucocratic biotite granite or adamellite poor in mafics, and intrudes the Herbert River Granite.

The granites in the Chillagoe district were subsequently revisited in 1960 and 1961 with this two-fold subdivision in mind, but it appears now that the situation is more complicated here. As a result of the field observations the granitoid rocks in the Chillagoe district have now been subdivided into six or more groups, generally with gradational, or at least obscure, boundaries:

1. Even-grained, medium crystalline, dark-grey or green-grey quartz dioritic to quartz gabbroic rocks (Pl. 8, fig. 2) with a colour index exceeding 25. The plagioclase is generally a labradorite or basic andesine, and constitutes 45 to 50 percent of the rocks, orthoclase makes up 5 to 15 percent, as does quartz, and the mafic minerals about 25 percent. The plagioclase is strongly zoned, as in virtually all the granitic rocks in the Chillagoe district. Biotite and hornblende are the principal mafic minerals; augite, in small grains, is subordinate, and is commonly mantled by hornblende. In some specimens hypersthene and monoclinic pyroxene are present (Pl. 9, fig. 1). Main areas of outcrop are south-west of Koorboora; around Petford; and on the western extension of the intrusion 15 miles west-south-west of Chillagoe.
2. Medium-grained, grey, hornblende-biotite adamellite and granodiorite, porphyritic in places. Plagioclase (andesine to oligoclase) generally predominates over the potash-feldspar, some of which is microperthite. Biotite and hornblende are present in about equal proportions, and rare grains of augite have been noted. This—the *Almaden Granite*— is a common rock type in the area between Almaden and the Walsh River, where, in places, it grades into the Herbert River Granite (which is not shown in this area on Plates 10. 11, and 12 because of the ill-defined and gradational nature of the boundaries between the two granites). Most of the copper-lead-silver and gold ores are associated with the Almaden Granite.

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* Branch (pers. comm., 1963) now considers the granites to be more or less contemporaneous, but of different origin. He is preparing a Bulletin for the Bureau of Mineral Resources which treats of the ring-complexes and associated igneous activity.

3. Fine, medium, or coarse-grained biotite adamellite with various amounts of hornblende: the *Herbert River Granite.* This forms the bulk of the outcrops south and south-west of Almaden. The plagioclase, with An20 to An25, is generally white, the potash-feldspar often delicately pale pink. Potash feldspar generally predominates slightly over oligoclase. Quartz constitutes from 25 to 40 percent of the rock, mafic minerals about 15 percent or less.

4. Leucocratic, pink-red, coarse alkali granite, poor in mafics. In the one thin section made, from a sample taken south of Batcha siding, the feldspar is mainly (kaolinized) microcline, microcline-perthite, and albite Albite also forms a thin clear rim around the other feldspars, particularly in strongly protoclastic zones, and may be the result of late-stage unmixing of feldspar. Biotite, the only mafic mineral, occurs in minute shreds and is very subordinate. Alteration products are chlorite, epidote, sericite, and magnetite.

   This rock type (the 'pegmatitic' granite of de Keyser et al., 1959) is distributed south of Batcha siding and along the northern rim of the Boxwood ring complex. Its boundaries appear to be comparatively sharp. Branch considers this a coarse phase of his *Elizabeth Creek Granite,* but field relationships suggest that it is slightly older than the normal Elizabeth Creek type (see page 30).

5. Fine, uneven-grained, commonly porphyritic or glomeroporphyritic, pink, leucocratic biotite granite poor in mafics. This is the typical *Elizabeth Creek Granite,* which constitutes most of the granite south of the Tennyson Ring Dyke. Associated with it are a number of varieties — porphyritic microleucogranite, alaskite, biotite granite, biotite micro-adamellite, and others. The maps include most of the 'aplites' and greisenized granites (as at Wolfram Camp and in the area south-south-east of Petford) under this heading also. The Elizabeth Creek Granite is intermixed with probable Herbert River Granite in the area south of the Tate River. The Elizabeth Creek Granite is of economic importance because it is the type of granite with which most of the tin, tungsten, molybdenum, and fluorspar deposits are associated.

   The feldspars consist of potash-feldspar (orthoclase, microperthite, and, in places, also microcline), generally in excess of plagioclase. Albite is an important constituent in some of the rock types, such as the alaskite. Biotite is not prominent, and hornblende is rarely present. In one or two thin sections fluorite was found among the accessory minerals. On the whole the texture is more xenomorphic than in the other groups. Fine myrmekitic textures between plagioclase and potash-feldspar, and graphic intergrowths between quartz and potash-feldspar, are fairly common. Graphic intergrowths have also been noted in some granites of the other groups.

6. The pink or grey, fine-grained, hornblende-bearing biotite microgranites forming the granite massif south of Petford and Lappa Junction are distinctive enough to be separated as an individual group. Potash feldspar (including microcline in some specimens) predominates over plagioclase (oligoclase-andesine), often sufficiently to allow the use of the term 'granite' instead of

'adamellite'. Mafic minerals are rather scarce (about 5 percent of the total mineral content), and biotite predominates strongly over hornblende. Characteristic of this group is accessory allanite, in scant amounts but persistently present.

Apart from these six groups there are odd varieties of granitic rocks of too small extent and with too vague boundaries to be shown individually on the maps. Within the Boxwood ring complex, in particular, the granites are rather diversified, and contain, amongst others, micro-pegmatitic or granophyric modifications (Pl. 9, fig. 2).

The granites in the Chillagoe district still present many controversies and problems. Furthermore, the distinction between Herbert River Granite, Almaden Granite, and Elizabeth Creek Granite cannot everywhere be made with certainty, as there appear to be intermediate types. Therefore, the boundaries between the various modifications as represented on the three maps (Plates 10, 11, 12) are tentative only, and are open to a good deal of future amendment.

Branch (pers. comm.) was at first inclined to ascribe the various modifications to assimilation and contamination: thus the grandiorite of the Almaden Granite was, in his opinion, the result of assimilation of Chillagoe limestone by Herbert River Granite. Assimilation of limestone by granite was seen in situ near the Hobson mine by W. B. Dallwitz, who recorded (pers. comm.) a gradation from wollastonite-grossularite-plagioclase-diopside hornfels (metamorphosed Chillagoe Formation) through porphyritic wollastonite-diopside microgranodiorite to porphyritic hornblende microgranodiorite. However, quartz diorites and granodiorites are not restricted to the limestone belts, but are also found in areas lying at great distance from existing or inferred pre-existing limestone formations, and assimilation as observed near the Hobson mine is therefore considered to be a strictly local phenomenon. Branch later revised his original idea of wholesale assimilation, though on different grounds (Branch, 1962), and he put forward the view that acid Herbert River magma had mixed with basalt magma to form hybrid granites such as the Almaden Granite.

Another granite modification in the district—our group 6—is regarded by Branch (pers. comm.) as contaminated Elizabeth Creek Granite, whereas we prefer to see it as a differentiate; there is as yet no concrete evidence for either opinion.

Magmatic differentiation may well have played at least as great a part in the formation of the various granite types as have assimilation and contamination by mixing. Wheeler (1955) describes varieties of granites in Labrador that form part of one adamellite batholith and that, he thinks, have resulted from differentiation without any important introduction of material. He subdivided the adamellite into hypersthene, hornblende, and biotite types similar to our groups 1, 2 and 3, and 4 and 5 (a fourth type—fayalite—is not represented in the Chillagoe

area). The more leucocratic rocks of the biotite type are younger than those of the other types. These features, and several others, apply to the Chillagoe granites also. From triangular composition diagrams Wheeler concluded that 'all the features fit a theory of magmatic differentiation'. The principle of differentiation, if applied to the granites of the Chillagoe district, would explain why the more basic granodiorites and quartz diorites are not restricted to limestone belts, and also why the leucocratic biotite modifications are younger than the others. And, although no diagrams have been made, it can be said that the relative proportions of quartz, potash-feldspar, and plagioclase in the various modifications of the Chillagoe granites seem to follow a trend similar to that of the Labrador adamellite varieties.

The Chillagoe granites and volcanics are expected to be treated against a wider and more regional background in a forthcoming Bulletin on the geology of the Hodgkinson Basin, by F. de Keyser and K. G. Lucas (in preparation).

Age and Relationships between Granites and Volcanics

The relations between the Permian igneous rocks have long been a problem to investigators, though the difficulties mainly arise from trying to fit all the granites and volcanics into single episodes. This mistake was avoided by Ball (1915), who distinguished a 'pre-granite' and a 'post-granite' porphyry, and by Jensen (1941), who, although claiming most of the porphyry as pre-granite, dated some, including the Tennyson Ring Dyke, as post-granitic.

Evidence showing granite younger than the adjacent porphyry includes: apophyses of aplite in porphyry (Wolfram Camp: Ball, 1919); porphyry matrix recrystallized (at Redcap and in the Emuford area), and adjacent granite finer-grained, probably chilled (Fluorspar area: Jensen, 1941; Wolfram Camp: de Keyser, 1959). Evidence showing porphyry younger than granite includes: inclusions of granite fragments in many of the porphyries, e.g., in the Tennyson Ring Dyke and the Boxwood Volcanics.

As mentioned before, de Keyser et al. (1959) subdivided the Featherbed Volcanics into three superposed groups, and considered all the granites as the differentiates of the one magma, and successively intruded during a long time interval. Branch (1961) assumed the existence of two volcanic and two intrusive periods in the Cairns hinterland area; however, in the Chillagoe district, the granitic relationships seem to be more complicated.

Subsequent fieldwork in 1961 has led to the distinction of the six groups mentioned in the previous pages. Some of them may be correlated with the Herbert River and Elizabeth Creek Granites; others may be products of contamination and assimilation—as favoured by Branch—or may be normal differentiates, like the example given by Wheeler (1955). Branch considers group 4 and 5 as coarse and normal varieties, respectively, of the Elizabeth Creek Granite. However, it was seen that the coarse variety occurs as inclusions in rocks of

group 6 (= contaminated group 5?), and also in volcanics of the Tennyson Ring Dyke, which are supposed to be intruded by Elizabeth Creek Granite. Thus we may have Elizabeth Creek Granites of two different ages, although the older phase (coarse) was possibly still hot when intruded by the younger phase.

The quartz diorites of group 1 are older than the Tennyson Ring Dyke, which cuts through them; dykes of quartz diorite adjacent to the Ring Dyke, when examined microscopically, appear to consist of strongly crushed rock.

Group 5 ('normal' Elizabeth Creek Granite) can be seen to intrude group 3 (Herbert River Granite) in the Khartoum district, north of the Tate River.

It seems that the various groups may have succeeded one another in the order 1, 3 and 2, 4, 5 and 6. Group 1 is regarded as the oldest member here because a general trend from more basic to more acid and leucocratic can then be recognised, and because Wheeler (op. cit.) has found the same conditions in Labrador.

The granites in the Cairns Hinterland have been systematically sampled in order to have their absolute age determined by means of the potassium-argon method. These determinations have been carried out in the Geochronology Laboratory of the Australian National University, Department of Geophysics, by Dr J. R. Richards and A. Cooper, and by A. Webb, of the Bureau of Mineral Resources. Results of their work have yet to be published at the time of writing, but the ages determined for the Herbert River Granite and the Elizabeth Creek Granite show spreads between 315 million years and 267 million years, that is, from Middle Carboniferous to Lower Permian. Samples selected from within the Chillagoe district gave the following results:

Almaden Granite, 1 mile west of Almaden—292 million years;
Elizabeth Creek Granite (or assimilated Herbert River Granite ? according to Branch, 1962), 4 miles south-west of Almaden—284 million years;
Elizabeth Creek Granite, Wolfram Camp—275 million years;
Herbert River Granite, 12 miles south-west of Chillagoe—285 million years;
(Dargalong Metamorphics, 7 miles south-west of Chillagoe—1044 million years, cf. page 15).

When plotting all ages determined from Herbert River and Elizabeth Creek types in the Cairns Hinterland, one notices that both types show a very considerable overlap in time, and also that all granites, regardless of type, become younger from south (Einasleigh 1:250,000 Sheet area) to north (Cooktown 1:250,000 Sheet area). Evernden & Richards (1962) had already described similar tendencies in the granites of the southern part of the Tasman Geosyncline, and it is advisable therefore to regard the granite modifications in the Chillagoe district as lithological types only, without attaching too rigidly defined age limits to them.

The results of these age determinations became available only after the maps and references had been drawn; hence the discrepancy between the text of this Bulletin and the Reference on the maps. The granites had been con-

sidered to be Upper Permian because the Almaden Granite seemed to intrude the Nychum Volcanics, which have been dated as Upper Permian on palaeontological evidence (de Keyser, 1961, and Morgan, 1961). However, it now seems quite possible that the field evidence had been incorrectly interpreted; inclusions of rhyolitic fragments in the granite which crops out alongside Nychum Volcanics in the Mossman 1:250,000 Sheet area (Morgan, 1961) need not be derived from these volcanics, and furthermore, the Almaden Granite here may theoretically be of a younger age than its representatives farther south. And at Wolfram Camp, the volcanics that are intruded by granite are positioned outside the cauldron area occupied by the Featherbed Volcanics, and hence may not belong to the period of Featherbed vulcanism but may represent an older, Carboniferous, phase.

Mesozoic

Lower Cretaceous sediments of the *Wrotham Park Sandstone* make their appearance in the western part of the Mungana Sheet area, where they transgress over the Dargalong Metamorphics and the Nychum Volcanics, and have been preserved as a fringe of mesas along the scarp of the Red Plateau. The thickness of the formation is variable, owing to differences of relief on the pre-Mesozoic land surface; a maximum of 250 to 300 feet can be estimated for the exposure within the Mungana 1-mile Sheet area.

The name 'Wrotham Park Sandstone' was introduced by Laing & Power (1959) for the Mesozoic sandstone sequence along the Chillagoe/Wrotham Park road, immediately north of the Walsh River; fossils found by W. R. Morgan (Bureau of Mineral Resources) on top of a small mesa in that area, in 1960, were identified by J. T. Woods (1961) as *Maccoyella barklyi*. The age of the formation was stated as lower Aptian by Laing & Power, as Neocomian by Woods (1961).

The formation consists mainly of cross-bedded, white or red, thick-bedded, feldspathic quartz sandstone; pebbly members and intercalations and lenses of conglomerate are very common, and layers of shale are also present.

The sandstone is texturally and mineralogically mature, well rounded and sorted, with grain-sizes ranging, with few exception, from 0.5 to 1.0mm. Mud cracks occur locally, and cross-bedding is well developed in many places and generally indicates that the direction of transport was from the east. In the north-west corner of the Mungana Sheet area the sandstone has disintegrated and now forms a thick blanket of loose white quartz sand. Locally in this part a kind of dense grey billy quartzite can be found; it is composed of sand-sized quartz fragments in a dense pale grey or cream siliceous matrix. Pebbles in the conglomerate reach a maximum size of about five inches, and are composed of quartzite, vein quartz, porphyry, chert, schist, and gneiss. The shale is light grey, weathering to rust red. It contains sandy laminae with worm tracks.

Where the unconformity at the base is exposed, it is seen to be overlain by a breccia bed three or four feet thick, and composed of fragments of the directly underlying Dargalong Metamorphics.

The eastern depositional limit of the Wrotham Park Sandstone is ill-determined, but it appears to have reached at least as far as Rookwood and Mungana. Jensen (1923) noted the close resemblance of friable quartz sandstone, occurring in pockets near Mungana, to the Mesozoic lithology of the western areas. Similar patches of sandstone were found near Rookwood Homestead during the 1958 survey. Their preservation in low-lying localities may be due to their being valley-fill deposits in the pre-Mesozoic topographic surface.

Cainozoic

Cainozoic deposits are scarce and unimportant. They comprise areas of residual sand, sheet-flood sediments, and isolated patches of stream alluvium.

Residual sands overlie parts of the granitic areas along the Tate River and Oaky Creek, and south of Wolfram Camp. A thick blanket of white quartz sand derived from disintegrated sandstone mesas is spread out along Tomato Creek in the north-western corner of the Mungana Sheet area, and contains outcrops of dense billy-quartzite.

Stream alluvium and residual soils are found in the belt occupied by the Chillagoe Formation, where soluble limestone and incompetent shale have permitted their formation and deposition in easily eroded valleys and plains.

Sheet-flood or piedmont alluvial deposits cover the area between Chillagoe and the Featherbed Range, and carry much volcanic rubble in sands overlying the granitic surface. They have been incised by Recent creeks.

True river alluvium is confined almost entirely to stretches along the Walsh River on either side of the Featherbed Range. Natural levees composed of sand and silt were built up along the river in the area occupied by the Dargalong Metamorphics, probably in pre-Recent times, as they appear to be incised.

STRUCTURE

The area has known at least two main periods of orogenesis—one in pre-Silurian time, a second during the Carboniferous. The first formed the Precambrian basement, which subsequently acted as a buttress at the time of the Carboniferous orogeny, when the Palaeozoic geosynclinal formations were tightly folded. This phase of folding was followed by isostatic readjustment, the mobile belt became more rigid, and fracturing reached a maximum during the Permian with the formation of ring complexes and cauldron subsidence blocks. Folding activity died out — the Permian formations show only broad, gentle folds. Vertical movements have continued up to Recent times, and many old faults were repeatedly rejuvenated. The best example of this is the great Palmerville Fault, which probably originated during the Upper Silurian with the downfaulting of an eastern block. Recurrent movements took place during Carboni-

ferous, post-Permian, and post-Cretaceous times (de Keyser, 1963), causing the eastern block alternately to rise and fall relative to the western block.

The Dargalong Metamorphics are strongly foliated; the foliation planes commonly dip steeply, although in some areas the dips are low to moderate. The foliation is generally parallel to the original bedding, but exceptions are found. Minor folding and crenulation, boudinage, and plastic folding are observable, but have not been systematically investigated. The general strike of foliation swings from north-east (in the western part of the Mungana Sheet area) to south-east (in the eastern part). The only effect the Carboniferous orogeny had on the Dargalong Metamorphics consisted of some internal strain and cataclasis, accompanied by retrograde metamorphism and faulting.

The geosynclinal Chillagoe, Mount Garnet, and Hodgkinson Formations are steeply tilted along north-west trends. Although very few actual fold axes can be recognised in outcrops or on air photographs, strong folding and overturning can be inferred from top and bottom relationships in the beds.

Amos (1961, 1962) has concluded from studies in the Mossman 1:250,000 Sheet area that folding of the geosynclinal formation took place in at least three or four stages under somewhat different stress systems. A first, tightly isoclinal folding phase resulting from horizontal compression was followed by a second stage of broader folding due to mainly lateral movement of material (probably because vertical movements at this stage were restricted by the load of the already folded sedimentary pile). The resulting steep plunges were determined by the intersection of the second-generation axial planes with the steeply dipping limbs of the first generation of folds. A third phase of deformation produced megascopic folds with intense axial-plane slaty cleavage.

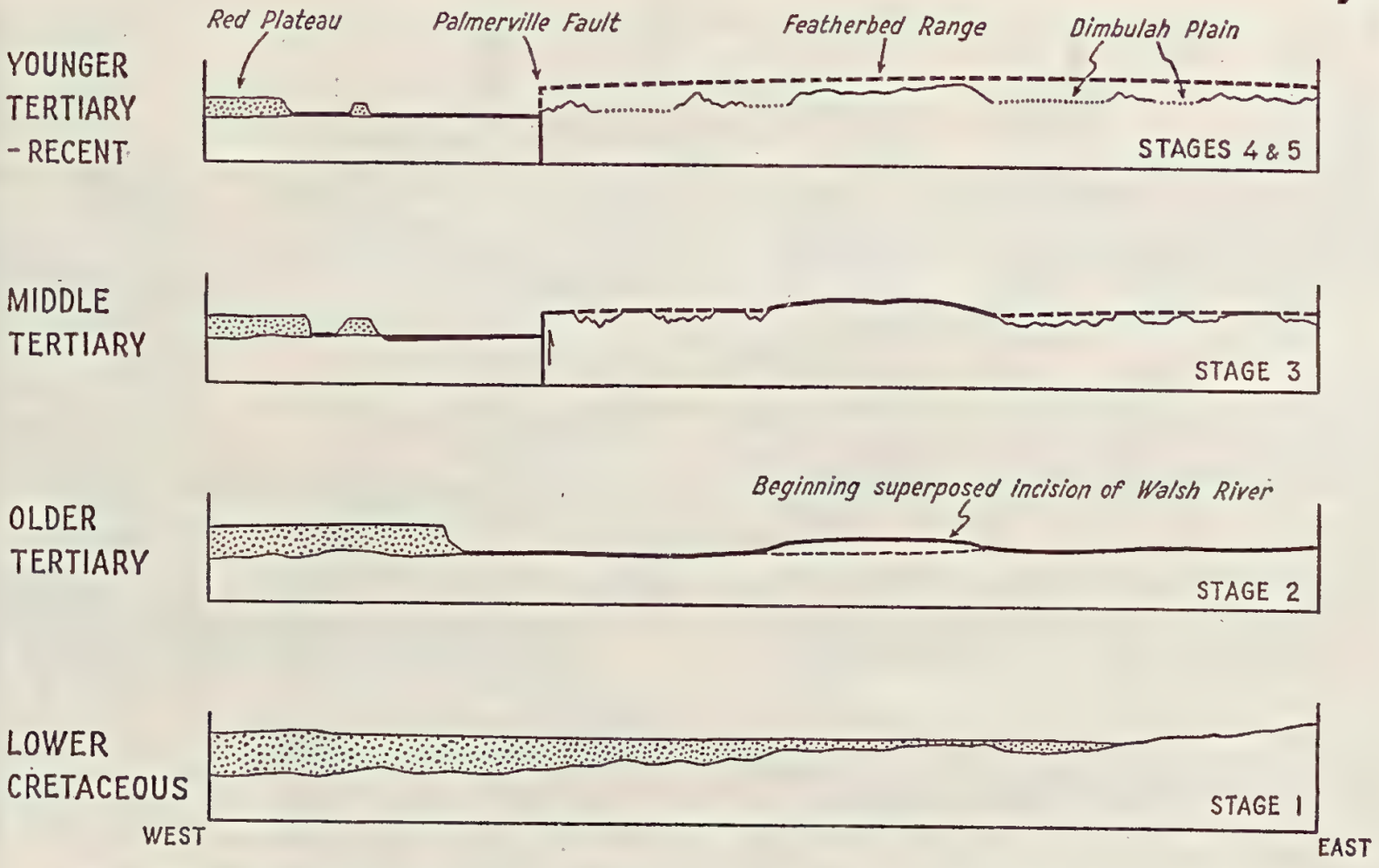
It is not known what relative intensity these various phases of deformation had in the Chillagoe area. Probably they are not all represented here owing to the dampening effect of the shallow Chillagoe shelf, over which the total thickness of accumulated sediments was probably far less than in the axial regions of the geosyncline farther to the north-east (outside the area), where thick deposits of flysch sediments (Hodgkinson Formation) were laid down.

Faulting during all these stages of deformation was intense, as has been recognised in the adjoining Mossman and Cooktown 1:250,000 Sheet areas. The faulting and fissuring assumed an unusual character during the Permian, when ring complexes and cauldron subsidence blocks were formed.

GEOMORPHOLOGICAL EVOLUTION

The area covered by three one-mile sheets is too small to be comprehensively analysed, and most physical features — relief and drainage — have been described in the Introduction. However, field work in the surrounding areas during the last few years has yielded much information, and the development of the present landscape, as sketched in the series of profiles (Fig. 7) and described below, is mainly based on such outside evidence.

Fig. 7



GEOMORPHOLOGICAL DEVELOPMENT, CHILLAGOE DISTRICT

..... *Younger Tertiary surface (Pliocene ?)*

——— *Older Tertiary surface*

Stage 1: Cretaceous transgression from the west over a low-relief, pre-Cretaceous surface of denudation. Deposition of Lower Cretaceous sandstone and conglomerate with a littoral facies at the base.

Stage 2: Uplift and erosion. Formation of one or two older Tertiary erosion surfaces. After the thin Cretaceous cover had been stripped, the Walsh River began its superposed incision into the Featherbed Range, which became carved out in relief because of its uniform toughness and the massive structure of its volcanics.

Stage 3: Renewed major movements along the Palmerville Fault caused uplift and warping of the eastern block. The older Tertiary surface became incised, and the beginning of a 'gipfelfluhr' was formed.

Stage 4: Younger broad valleys and plains — e.g., the Mareeba - Dimbulah Plain — were formed, possibly during the Pliocene. The superposed incision of the Walsh River continued. Possibly the climate at that time was wetter (see below).

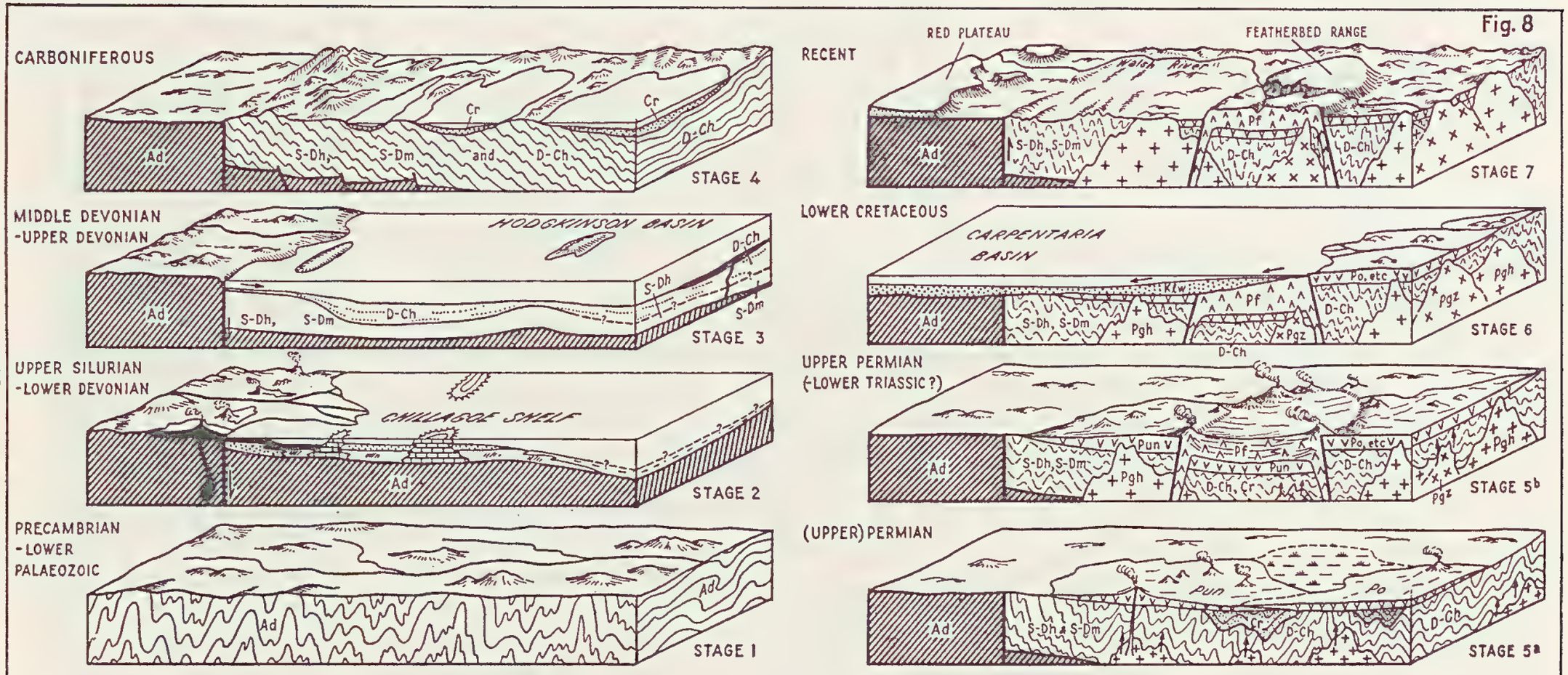
Stage 5: (not represented in the diagrams). In Pleistocene to Recent times earth movements continued to a greater or lesser degree. Faulting and fissuring is in evidence in the Mossman and Atherton areas, and may be assumed to exist in the Chillagoe district as well, thus explaining the sudden changes of relief in some granite areas such as the one south of Petford. The incision of large alluvial plains, e.g., west of the Featherbed Range, may be due in part to renewed uplift or else to a change in climate. Change of climate is here also held responsible for the formation of the so-called 'Metal Hills' granite outcrops north-west of Chillagoe: it is thought that, after the dwindling of the rich vegetation from the previous wetter period, the soil and weathering mantle was easily stripped off from the most prominent (but not necessarily the most elevated) parts of the granite topography, so that the core-mantle became exposed, and degenerated to a naked boulder mantle on which no soil can form owing to the stripping action of heavy rain during the wet season, and the arid conditions in the other half-year.

GEOLOGICAL HISTORY

Figure 8 shows, in a series of diagrams, the most likely sequence of the main geological events. The post-Mesozoic history has been treated in the foregoing chapter on geomorphological evolution.

Stage 1: A Precambrian sequence (Ad) of arenites and pelites with interbedded basic volcanics was folded, metamorphosed, and partly granitized. After isostatic uplift a long period of denudation led to the formation of a mature to old landscape.

Fig. 8



GEOLOGICAL HISTORY, CHILLAGOE DISTRICT

Stage 2: A shallow sea transgressed this land in the east, during the Upper Silurian, possibly as the result of the appearance of the Palmerville Fault, along which an eastern block was gently down-faulted. It was the beginning of the Tasman Geosynclinal subsidence in this part of North Queensland. Sediments of the Upper Silurian Chillagoe Formation (S-Dh) were deposited in a shelf area, and represent a mixed shelf association of reef limestone, with arenites and siltstone laid down in deltaic sectors, and chert probably in quiet and isolated lagoons. The Chillagoe shelf area can be termed a miogeosyncline, if a miogeosyncline may be defined as the more stable marginal part of a geosyncline, forming the transition into the craton (see Kuendig, 1959). Basic extrusives are present in this miogeosyncline, and this is an exception to the generally accepted 'rule' that miogeosynclines do not experience igneous activity. They may have accompanied the generation of the Palmerville Fault, subsidiary fissures of which may have served as feeder channels to the basic volcanics: basic dykes parallel the fault in many places.

Within the area mapped, the mixed shelf association of the Chillagoe Formation was followed by the clastic shelf association of the Mount Garnet Formation. In other regions outside the Chillagoe district the Mount Garnet Formation (S-Dm) as a facies type seems to have replaced the Chillagoe Formation; the two formations are probably partly penecontemporaneous. It is conceivable that the clastic shelf assemblage of the Mount Garnet Formation was deposited when—or in places where—erosion in the bordering continent was more active.

Chillagoe and Mount Garnet sediments have not been found in areas towards the centre of the Tasman Geosyncline, to the east of the area mapped. It is assumed that towards these deeper parts the sediments deposited during the Upper Silurian were much finer, forming uncharacteristic slate and siltstone sequences which may be actually exposed, but not recognized, in parts of areas mapped as Hodgkinson Formation and so-called 'Barron River Metamorphics', between Cairns and the Chillagoe district. Such sediments, though time-equivalents of the Upper Silurian Chillagoe and Mount Garnet deposits, would not be distinguishable from the fine-grained members of the Devonian Hodgkinson Formation, because they were deposited under essentially the same conditions.

Stage 3: From about the Middle Devonian, subsidence of the geosynclinal trough accelerated, and depth of deposition increased. The area of shelf facies probably shrank considerably, while greywacke and siltstone were deposited on a large scale, partly by turbidity currents and submarine sliding. Interbedded shale and chert probably represent the 'normal' facies of continuous deposition. Basic and acid volcanics—spilite, andesite, quartz keratophyre (though not represented in the Chillagoe district)—were extruded. This succession of sediments and volcanics forms the Hodgkinson Formation (D-Ch). The sediments may be

regarded as representing a flysch facies (see page 27), although some authors distinguish between a flysch facies and a greywacke facies.

Some workers, for instance Jones (1943), think that there was a folding phase between the deposition of the Chillagoe (Mount Garnet) Formation and the Hodgkinson Formation, during the (?) Lower Devonian; Jones nevertheless confessed that there was no valid evidence for such an orogenic phase. White (1961) presented evidence for an unconformity in the region south of the Chillagoe district, but such an unconformity could not be proved in the Chillagoe area. Nevertheless, White's concept of a tectonic land to the south would not be incompatible with the lack of an unconformity in the north: the rise of land in the south would first supply abundant detritus (thick Mount Garnet deposits near Mount Garnet), diminishing to the north (thinning of the Mount Garnet Formation, and its final disappearance north of the Mitchell River). With continuing rise during Devonian times the formation of a definite unconformity between the Mount Garnet and Hodgkinson Formations was possible in the south, grading northwards into a disconformity and finally into an uninterrupted sequence. In the Chillagoe district, however, the contact between the Mount Garnet and Hodgkinson Formations is not exposed, so that conclusions cannot be drawn from this area.

Stage 4: Beginning of the Carboniferous orogeny. The Silurian and Devonian formations were folded and partly elevated above sea-level, and in the isolated or narrowed marine and continental basins quartzose sandstone and siltstone and some conglomerate were laid down with angular unconformity. They are possibly comparable to 'molasse' deposits. Remnants of such Carboniferous formations are probably represented, within the Chillagoe district, in the areas of Boxwood and Koorboora (?Ringrose Formation, Cr). Continued compressional forces folded these Carboniferous deposits, too.

Stage 5: Compressional stresses ceased, and during the following isostatic re-adjustment the region was elevated above sea-level; a long period of denudation set in, transforming the area to a mature old plain of low relief.

Granites, which had possibly been generated during the Carboniferous orogeny by differential melting and fusion of the deeper parts of the sedimentary pile, at depths of about 5 miles, were probably subjected to over-heating, which enabled them to work their way upwards for considerable distances without (immediately) solidifying, and finally crystallized as high-level plutons — the Herbert River (Pgh) and Elizabeth Creek (Pgz) Granites. Meanwhile, tensional faulting and fracturing provided supply channels for coeval and co-magmatic volcanic extrusions; ring complexes were formed, and the final stage was the formation of a large cauldron subsidence block in which large volumes of welded tuffs and lavas were poured out (Stage 5b).

Stage 6: Erosion and denudation, which had started to plane down the landscape after the Carboniferous orogenic uplift, continued during the Mesozoic. During the Lower Cretaceous transgression, which encroached from the west, sandstone and conglomerate of the Wrotham Park Sandstone (Klw) were deposited in the littoral environment of a shallow sea. This sandstone facies was succeeded by the marine shale facies of the Blackdown Formation (Klb).

Stage 7: Epeirogenic movements and faulting elevated the area once again above sea-level, and post-Cretaceous vertical movements combined with erosion to form the present-day landscape. This phase has been described in more detail on page 48.

ECONOMIC GEOLOGY

INTRODUCTION

The area covered by the one-mile Sheets of Chillagoe, Almaden, and Mungana ('the Chillagoe district') contains most of the old mining centres within the Chillagoe Gold and Mineral Field, and includes small corners of the Herberton Gold and Mineral Field and the Mareeba Gold and Mineral Field. During its life it has produced copper, silver, lead, gold, tungsten, molybdenum, bismuth, tin, cobalt, zinc, and iron minerals, fluorspar, and lime; minor uneconomical occurrences of mica, silica, clay, coal, antimony, cobalt, manganese, and titanium minerals are also known. The workings are almost all inaccessible—collapsed or filled with water—and the information compiled in the following pages has been collected from many various sources.

Mining History

The first official record of the presence of mineral deposits in the Chillagoe district appears in the Annual Report of the Department of Mines (Queensland) for the year 1888: it states that one of the managers of Messrs Moffat and Company, while searching for a dray road from the 'copper mines in the Chillagoe district' to the east, had found tin at Koorboora. It appears that the existence of these copper and silver lodes had first been mentioned to John Moffat, one of the mining pioneers on the Herberton tin field, by Mr Atherton, an early settler of Chillagoe. By the end of 1888 Moffat employed more than 70 men on testing and development work on deposits around Chillagoe, Redcap, and Mungana.

Jack (1891), Skertchly (1897, 1899), and Dunstan (1900) were the first geologists to describe these deposits. Although they were unanimously of the opinion that the district had very great potential, activities at first remained restricted to further prospecting and non-productive development, largely because of the lack of a good transport link through the rough country to the east. The only production during this time came from tin placers around Koorboora.

To remedy the situation several small smelters were erected to treat the ores locally: examples were the smelter at Muldiva, built in 1891, for the silver-lead ores, and the copper smelter at Calcifer, built in 1894 by the Irvinebank Tin Mining Company. However, only the rich ores could be treated effectively, and soon the need was felt for a central plant able to treat the lower grade ores, and for a good transport link to the east to export the matte. As a consequence the Chillagoe Railways and Mines Co. Ltd. was formed and, in 1897, began the construction of a railway line from Mareeba to Chillagoe and Mungana. In 1901 the last stretch was completed, and in the same year a large smelting plant was opened by the company at Chillagoe.

The Chillagoe district now entered its most prosperous period, which lasted until about 1914 for the base metals, and until 1920 for tin, tungsten, and molybdenum. The base-metal deposits were almost all mined by the Chillagoe Railways and Mines Co. Ltd (known as the Chillagoe Co. Ltd from 1905 to 1913, and as Chillagoe Ltd from 1913 to 1915) and by its subsidiary, the Mungana (Chillagoe) Mining Company. Wolfram Camp and Bamford Hill became the most important wolfram producers in Australia. The overall peak of production was reached in 1908. After that year a gradual decline set in, brought about by strikes, lower metal prices, mining difficulties, fires in one of the largest producers (the Lady Jane), and other factors. Several mines, including important ones like Zillmanton, Ruddygore, and Lady Jane, closed down. Much of the capital backing the companies was German and was frozen when war broke out in 1914. The smelters stopped operating, entailing a severe setback for the surviving base-metal mines: the only important copper producer left during the war years was Cardross. However, the wartime demand for tungsten and molybdenum kept the Wolfram Camp and Bamford Hill mining centres going.

In 1918, the Queensland Government, wishing to prevent the total decline and eventual abandonment of the area, took over the assets of the company, re-opened the smelters in 1920, and continued mining. A second but shorter and less intense boom followed; in 1923 silver-lead again reached a high peak, but copper production remained rather low. Fluorspar entered the list of minerals found, and its production culminated in 1925.

However, the average grade or the ores had dropped considerably, and the Chillagoe smelters, not equipped to deal with the low-grade material, were forced to bring in large quantities of rich ore from such outside areas as Etheridge and Herberton, and from as far as the Cloncurry district. Mining in the Chillagoe area itself languished and grew stagnant. When circumstances forced the smelters to close down temporarily in 1927, the mines had to follow suit, but they lacked the vitality to revive when the smelters re-opened in 1929. The bulk of the ore henceforth was imported from outside districts. In 1943 the smelters were closed for the last time and were finally sold for removal in 1950.

Minerals other than the base-metal ores caused a slight recurrence of activity after 1930, when gold was found near Fluorspar, and interest in the Mount Wandoo gold mines reawakened. Gold, fluorspar, and wolfram became the dominant minerals won. However, production gradually declined, and at the time of our survey in 1958 mining had come to a virtual standstill: only insignificant quantities of cassiterite, fluorspar, and molybdenite were being won.

In 1961 a good tin lode was being successfully reworked at the Dover Castle tin mine, but all other minerals had completely dropped out of the picture. At present Mungana is deserted, part of the railway has been abandoned, and the remaining services have been reduced.

Mineral Exploration

No systematic exploration was made during the early days: the numerous ferruginous-siliceous and skarn outcrops were obvious enough. In later years the various deposits were visited and described by a succession of Queensland State Government geologists. At the beginning of World War II Jensen (1941) mapped in detail part of the Chillagoe district, and gave a full and comprehensive description of its many workings. Broadhurst (1953), a consulting geologist, did much detailed work in a more restricted area between Mungana and Chillagoe. In 1958 a combined geological party of the Bureau of Mineral Resources and the Geological Survey of Queensland undertook the systematic mapping of the area as a whole, and located and described its many workings.

After the end of World War II several mining companies took renewed interest in the district, and Authorities to Prospect were issued, among others, to Broken Hill South Ltd for the Mungana-Redcap areas and Ruddygore (1947-1951); to Clutha Development Ltd for the western part of the area (1956-1958); to New Consolidated Gold Fields Ltd for the eastern part (1957-1958); to Metals Exploration N.L. (1956) for the Redcap area; to the Chillagoe Prospecting Syndicate for the Mungana area (about 1955-1956); to Enterprise Exploration Pty Ltd (1961) for the Chillagoe-Almaden area; and to Broken Hill Pty Co. Ltd (1960-1961) for the Sunnymount and Koorboora areas. During their exploration activities churn and diamond drilling was put to use at Ruddygore, on Moffat's Hill, and on the Griffith Lease in the Mungana district, and in the Redcap and Cambourne (Redcap) areas. The latest drilling tests were carried out by Mount Isa Mines Ltd at Ruddygore (1960), and by Broken Hill South Ltd at Cardross in 1962-1963.

Geophysical methods were first put into practice in 1930 in the Redcap and Mungana areas by the Imperial Geophysical Experimental Survey (Broughton Edge & Laby, 1931), but the results were inconclusive, and the survey was criticized by Ball (1931), who observed that only a hurried reconnaissance had been made, that only an unchecked equipotential method had been used, without the assistance of a geologist familiar with local conditions, and that '. . . on the work done, they should not have been expected to select sites for boring'.

In 1949 the Commonwealth carried out electromagnetic surveys in the Redcap, Mungana, and Zillmanton areas (Langron, 1957). An airborne scintillometer was used in 1954 by the Bureau of Mineral Resources over a large area, including the Chillagoe Field (Parkinson & Mulder, 1956). This was followed up by a more closely spaced combined magnetometer and scintillograph aerial survey of the Chillagoe area in 1958. The following year geophysical work was done at Ruddygore and Wolfram Camp (Horvath, 1959; Daly, 1959). In 1961 Mineral Deposits Ltd (Southport) carried out a magnetometer survey around the iron deposits of Mount Lucy, west of Almaden.

Geochemical prospecting methods were tried out by the Bureau of Mineral Resources in 1961 around Redcap, Ruddygore, and the old Khartoum district, and in the area south-west and south-east of Almaden. A more detailed sampling system was tested by Enterprise Exploration Pty Ltd in the same year. The results indicate that the geochemical technique is workable in these areas.

Production

Table 2 gives the annual production figures for the various minerals won in the Chillagoe district—the area covered by the three one-mile Sheets of Chillagoe, Almaden, and Mungana. Figures 10 - 14 show graphically the production of the most important minerals won. The total production has been valued at more than £2,500,000.

In the early years output was not accurately recorded, but from 1891 the production figures appeared in the Annual Reports of the Queensland Department of Mines, and were included in the records of output of the Herberton Mining District (Walsh and Tinaroo Mineral Field). In 1909 the area was included in the newly designated Chillagoe Gold and Mineral Field. Wolfram Camp was detached from this field in 1949, and incorporated in the newly designated Mareeba Gold and Mineral Field.

Considered objectively, the Chillagoe district has been over-rated as a base-metal mineral field. The area contains hundreds of mines and prospects, yet, during its entire life span, its total output of lead has been only about 20 percent of the 1960 production of Broken Hill, or 85 percent of that of Mount Isa, and is only five times that of the 1960 production of Captains Flat. Its total copper yield has been 33 percent of that of Mount Isa for the year 1960, and only twice that of the 1960 Mount Lyell copper production.

Wolfram has been relatively much more important. Wolfram Camp, with a total production (to end of 1960) of 5400 tons—about a third of the total production to the end of 1960 of Australia's main tungsten producer, King Island —was once the major wolfram centre of Queensland.

Before 1920, when the world's consumption of molybdenum was very much smaller than it is now, Australia was the leading producer of this metal, and the Chillagoe Field was the main centre. However, in modern perspective, this is an unimpressive fact—the Chillagoe Field's total molybdenum output during its entire productive period amounts to less than 4 percent of the 1961 production of the Climax mine in the United States.

As a goldfield, the Chillagoe district attracted considerable attention during the thirties, and there was a continual small production of gold as a by-product from the base-metal mines, but the recorded total is insignificant; it amounts to about 8 percent of the 1961 production of the Lake View and Star gold mine in Western Australia.

TABLE 2

PRODUCTION TABLE OF ORE PRODUCED FROM THE AREA EMBRACED BY ALMADEN, CHILLAGOE AND MUNGANA ONE-MILE SHEETS

Year	Silver (oz.)	Gold (fine oz.)	Gold (Bullion)	Copper (tons)	Lead (tons)	Silver-Lead (Bullion) (tons)	Zinc (tons)	Tin Oxide (tons)	Wolfram (tons)	Scheelite (tons)	Molybdenite (tons)	Bismuth (tons)	Bismuth Wolfram (tons)	Wolfram Molybdenite Mixed Concentrate (tons)	Fluorspar (tons)	Antimony (tons)	Mica (tons)	Rutile (tons)	Clay (tons)	Quartz Crystal (tons)	Silica (tons)	Limestone (tons)	Ironstone (tons)
1891	1,856			27																			
1892				20				10															
1893	187,571							56															
1894				212				3	65														
1895	9,000			275		59			21														
1896	3,810			328		30																	
1897	31,992			147	250	401			13														
1898									68			1											
1899								37	270														
1900								105	188		11	5											
1901	15,721	75		367				168	72		9	6	17										
1902	23,792			402				116	55		38	1	3										
1903	351,263			2,119	3,636			150	188		10	.2	13									3,698	8,721
1904	357,197	31		1,446	1,661			112	652		21	2.1	3									4,017	4,424
1905	238,326	121		1.005	1,585			144	815		64	7	20									4,434	2,627
1906	347,513	77		1,665	1,715			265	488		92	5	22									5,971	3,364
1907	488,152	367		2,026	4,370			352	433		63	6	11									9,685	5,708
1908	638,100	94		2,170	6,356			251	229		112	12	147									13,396	2,960
1909	541,746	114		1,998	4,568			572	354		91	4	64									14,550	1,036
1910	340,261	23		1,623	981			589	496	2	104	7	14									15,557	3,403
1911	128,826	85		741	920			320	216	5	99	4	98									11,870	2,280
1912	175,765	133		327	1,859			385	116		101	3	147	23								12,929	2,965
1913	197,636	557		630	2,273			347	76		64	2	174	146								9,100	2,797
1914	27,032	171		176	260			133	64		76	.7	180									1,224	523
1915	32,922	769		593	17			166	144		92	1.2	224									2,500	
1916	4,726	50		94	6			117	84		75	2	126									805	
1917	17,096	6		204	16			75	122		106	3	121									973	
1918	3,015	92		61				90	105		90.5	1	111									738	
1919	122	.1		1				66	87	1.5	74	.7	133									2,355	
1920	72,385	2.7		217	1,070			19	50		23	.6	48		603							3,879	
1921	95,292	.3		101	881			23	4		9				536							10,991	181
1922	190,267	3.4		63	2,338			1	1			1										2,565	
1923	375,158	98		651	4,871			18			9	.2										8,580	200
1924	247,264	1.4		472	3,494		130	55	1		3	.2			1,864							4,987	
1925	184,928	.3		184	3,116			46	5		2	.5			4,227						168	6,782	345
1926	104,484			89	1,839		200	49	.5						2,311						389	6,484	4,412
1927	23,706	8.7		8	401			58			1		6		1,033							1,282	506
1928	556			4				76	27			.8			1,125							1,548	
1929	14,168			16	224			45	8						592							3,342	1,236
1930	12.008	140		40	57			27	6	.3	2		1.5		751						223	8,873	1,149
1931	1,107	967	298	51	.5			25			.3				521							9,767	798
1932	5,669	925	880	27	.2			23	6	1	1				1,220						83	13,429	578
1933	4,790	2,233	540	16	.8			29	13		4				737						118	11,413	1,434
1934	4,461	1,767	605	21				38	29		1				1,307				51		24	9,138	887
1935	7,135	1,719	400	149				15	22	.1	10	.1			182				50		50	2,761	946
1936	5,386	1,157	95	104	1			36	19		17	.1			479				158			4,604	2,236
1937	4,699	519	19	40	1			77	24		13	.1			920				176			6,367	4,290
1938	936	161		21	.8			20	54		7	.2	1		2,435				159			6,276	5,125
1939	147	115	12	.2				13	42	.1	7	.5	.7		20				217			9,740	3,940
1940	1,228	327	77	40				78	62		3	.3	.1		874				177		106	7,860	2,841
1941	988	118		32				35	38		6	.8	.1		144				134		137	6,245	2,312
1942	186	124		4				35	58	.7	9	.8	1		306		.1		90		74	6,230	3,469
1943	13	14						34	73		9	.7	1		535				33	.7	67	3,959	960
1944		.7						20	122		1	.9	1.5		512							3,390	
1945		11						22	87			.8	.1		788							5,009	
1946								9	31		8	.5			593							4,724	
1947	3							11	35		1	1			741	.5						3,448	
1948								6	38		2	1			288							4,896	
1949								20	26		5	.2			377							4,864	
1950	137	.3		.5				18	16		3.5				595							3,862	
1951	467				14			5	23		.2				277							3,204	
1952								20	53	.4	.1				85							3,087	
1953				1.4				22	51		2				206							3,300	
1954				1				64	21		.7				240							2,930	
1955		65		7.3				17	41		3							1.7				2,380	
1956								22	27													2,298	
1957								14	7		3											2,001	
1958								4.7	.2		4.5											3,360	
1959								76.7														2,555	
1960								63.7														3,610	
TOTAL	5,521,258	13,250	2,926	21,067.4	48,701.3	490	330	5,941.1	6,541.7	10.1	1,564.8	85.5	1,689.0	169	27.424	0.5	0.1	1.7	1,245	0.7	1,439	329,822	78,673

Silver quantities compare a little more favourably; Chillagoe's total silver production was more than a third of the highest total annual silver production yet recorded in Australia.

The main interest of the Chillagoe district lies in the diversity of its mineral deposits, and in its latent potential for rare metals that may occur in some of the greisens and pegmatites in the area.

DISTRIBUTION AND CLASSIFICATION

Mineralization is widespread and varied in the Chillagoe district; nevertheless, several generalized groups can be recognized, each characterized by its own specific mineralization and geological conditions (Pl. 13). The majority of the lodes lie in the sedimentary formations; a few—most of the tungsten and molybdenum deposits—are found in granite. The Featherbed Volcanics are almost devoid of mineral deposits, with the exception of the Lappa Lappa lead and tin mines north-west of Petford and Bamford Hill.

In Figure 9 an attempt is made to fit most of the mines or groups of mines into a classification that is based on both the character of mineralization and the structure of the deposits. High-temperature pneumatolytic to hypothermal conditions appear to have prevailed. No epithermal lodes have been recognised. All deposits in the area can probably be linked with the intrusion of the Permian granites and granodiorites, with the single exception of the Mount Kitchin mica pegmatites.

Most of the ore was won from the oxidation zone or from zones of secondary enrichment; with greater depth conditions usually became unfavourable, either because of a change in mineral composition (increase in sphalerite in the lead ores, for instance) or because of the uneconomic grade of the primary ores. In many places technical difficulties also increased, owing to such natural troubles as copious influx of mine water or the softness of clayey wall rocks.

The depth of the groundwater level in the Chillagoe belt generally ranges between about 50 and 100 feet, but the zone of oxidation in places extends well below the water level, probably owing to a free and fast groundwater circulation through the cavernous limestone masses.

Smirnov (1959) has noted that in Russia the axial parts of a geosynclinal area are usually the sites of tin, tungsten, and molybdenum mineralization, whereas the peripheral parts are commonly characterized by contact-metasomatic and hydrothermal sulphide deposits. The same seems to apply to the ore distribution in the Chillagoe district and the adjoining Mossman Sheet area: the tin, tungsten, and molybdenum mines are found towards the axial parts of the Tasman Geosyncline, whereas the copper, lead, zinc, and silver lodes are concentrated along its western margin.

Fig.9

TENTATIVE CLASSIFICATION OF THE ORE DEPOSITS IN THE CHILLAGOE DISTRICT

	PEGMATITES	CONTACT DEPOSITS	FISSURES, SHEARS, PIPES	DISSEMINATIONS
MESOTHERMAL			*Dargalong* *Pb — Ag* *Fluorspar* *Au, F*	*Ruddygore*
			Fluorite veins? *Mount Wandoo*	
HYPOTHERMAL		*Zillmanton* *Mungana* *Redcap*	*Cardross* *Dover Castle* *Koorboora & Sunnymount* *Khartoum* *Bamford Hill* *Wolfram Camp*	
PNEUMATOLYTIC		*Muldiva* *Christmas Gift* *Boomerang, Hobson* *Ti-tree, Mount Lucy* *Chillagoe Consols* *Harper*		
PEGMATITIC	*Mount Kitchin mica*			

All important copper-lead-zinc-silver deposits in the Chillagoe district occur within a belt 30 miles long and roughly six miles wide, stretching from near Almaden to the Mungana and Redcap areas. They are generally associated with the limestones of the Chillagoe Formation, which are intruded by the Permo-Carboniferous granites and granodiorites and have been locally transformed by contact-metamorphism and metasomatism to marble, calc-silicate and skarn rocks, and magnetite and hematite-quartz lodes. Jensen (1940) thought that, in general, the more basic differentiates of the granodiorites produced wider and more ferruginous belts of contact alteration than did the acid varieties, and that copper was mostly concentrated within the garnetiferous belts, whereas the lead lodes were generally not associated with garnet rock. He also suggested that the lead lodes have a narrower, but well-defined, compact, and jasperized 'ironstone' cap. However, one has only to examine the abundant garnet rock deposits at the Muldiva lead mines to come to the conclusion that at least some important exceptions do occur.

The usual order of formation in contact deposits is: calc-silicates-magnetite-sulphides, and the Chillagoe lodes generally appear to follow the rule. Noteworthy is the opinion expressed by Dunstan (1906) and by Denmead (1934d) that the magnetite-hematite mixtures at Mount Lucy are probably the result of surface concentration due to weathering and alteration of garnet, and its replacement by magnetite. This conclusion was based on the observation that in that and other localities the iron oxides gave way to garnet rocks at small depth whenever shafts were sunk.

Typical contact deposits are generally known to be irregular and unpredictable, though knick-points in the contact surface and embayments of limestone in granite seem to be favourable loci for ore concentration. The Chillagoe contact lodes are no exception, and as the easy-to-find surface deposits have all been found and have for the most part been worked out, a search for deeper deposits of ore will eventually have to be made by drilling and geophysical means, should increased demand for base metals warrant further prospecting. At present such a proposition is quite unattractive: besides being difficult to find and to assess, individual deposits are generally small and not of very high grade.

Other deposits, probably also of high-temperature origin, but more regular in configuration, are those occupying fault or fissure zones, such as the Chillagoe Consols and the lodes at Zillmanton, Redcap, and Mungana. Geophysical exploration has outlined a considerable length of possible ore-bearing structure at Zillmanton, but this work has not been followed up by test-drilling (Langron, 1950; Branch, 1960).

The pipes of the Girofla and Lady Jane mines (pages 65, 66) and the breccia of Mount Redcap are much-discussed and controversial subjects. The Redcap breccia was considered by Jack (1891) as well as by Broadhurst (1952) to be a volcanic breccia, and by Jensen (1941) to be a fault breccia, but these explanations are here rejected (see page 23). Broadhurst also considered the

Girofla and Lady Jane pipes to be volcanic diatremes. However, we envisage a hydrothermal-pneumatolytic origin by which the corrosive action of fluids and vapours transformed the limestone in their pathways into chert, and consider that brecciation was brought about by cracking due to changes in volume and pressure (see also page 23). The pipes may be aligned on faults or shear zones, as at Redcap and possibly at Mungana.

The Ruddygore copper mine (page 71) is different from the other mines; it is a disseminated deposit of the 'porphyry copper' type, probably formed under mesothermal conditions. Metasomatism of the granodiorite, and mineralization, were attributed by both Broadhurst (1949) and Branch (1960) to the most acid differentiates of the granite, called 'aplites' by Broadhurst, 'leucocratic micro-granodiorites' by Branch. The cracking and brecciation of the orebody may have been due to mineralization stoping, as advocated by Broadhurst, or to upward pushing of the acid differentiate, as favoured by Branch, or to a combination of these processes.

There seems to be a suggestion that the purer silver-lead ores, poor in copper, are the farthest removed from the granite contacts, and that copper is predominant where granite outcrops are very near, or where granite is suspected to be present at shallow depth.

Ovchinnikov (1959) found (partly by experiment) that, when a granite melt becomes contaminated with lime-rich rocks, it is likely to produce iron and copper ores at the granite-limestone contact by means of a kind of natural flotation process. Gas escape is localized in segments controlled by faults and fissures; the gas may even force its way upwards 'under its own steam', thus forming 'gas breccias'. Orebodies may be formed in contact-metasomatic skarns and hydrothermal deposits. The Chillagoe district, with its cupriferous iron contact deposits commonly controlled by faults and fractures, and with its breccia pipes, might serve as an ideal illustration to the ideas expressed by Ovchinnikov.

The copper lodes scattered around Cardross in the Dargalong Metamorphics have a more hydrothermal character, though the presence of such minerals as magnetite, tourmaline, topaz, fluorspar, and wolframite, and the kind of wallrock alteration, point to deposition under still high temperatures. They differ from the copper lodes in the Almaden-Mungana belt also in the absence of appreciable amounts of lead and zinc, and in their comparatively high gold values.

The belt of fluorite veins south-west of Chillagoe and Almaden runs approximately parallel with the Palmerville Fault; the numerous veins may, perhaps, have been emplaced in secondary fissures formed during one of the stages of movement along the Palmerville Fault.

The gold deposits at Mount Wandoo and Fluorspar are probably mesothermal metasomatic and vein deposits. Arsenopyrite is their most common non-commercial metallic gangue mineral.

The tin lodes of the Koorboora and Sunnymount areas may be the result of two phases of mineralization—one with a more pneumatolytic, the other with a more hydrothermal character. The high-temperature phase would be represented by the tin-wolfram association, and by the pneumatolytic alteration of wall-rocks (formation of mica and tourmaline); the hydrothermal phase is probably characterized by the sulphide paragenesis and perhaps by the chloritization of wall-rocks. This two-phase emplacement may explain the apparent reversed order of mineral zoning in the lodes: according to several reports the tin ores tend to give way to sulphides in depth. Within the high-temperature sequence the mineral zoning is 'normal': the upper parts of the cassiterite lodes commonly contained appreciable amounts of wolframite. The tin lodes are all associated with the ring complexes of Boxwood and the Featherbed Ranges. A possible two-phase mineralization could perhaps be explained in the terms of this environment: a first phase of normal hydrothermal activity, followed by a phase of high-temperature mineralization due to the foundering and sinking of large blocks to a depth of several thousand feet below their original level. On the other hand, Blanchard (1947), in his discussion of the Tennyson tin pipes, states that the sulphides, which are intimately intergrown with the cassiterite, do not show any preference for any part of the lodes, and he considered that the sulphides and the cassiterite were precipitated simultaneously.

The tungsten-molybdenum-bismuth deposits of Wolfram Camp and Bamford Hill are situated in greisenized granite cupolas which have only recently been uncovered by erosion, as is evidenced by remnants of the original sedimentary and volcanic cover on some of the granite tops at both Wolfram Camp and Bamford Hill. The irregular pipe-like bodies have been puzzling features since their first discovery. Cameron (1904) thought that the pipes were formed where joints intersected. Ball (1920) envisaged magmatic stoping along joint intersections, followed by introduction of colloidal silica and, later, of ore metals precipitated from fluids and vapours. He illustrated with a diagram how the tortuous pipes might have been developed along such joint intersections. Jones (1943) favoured igneous injection governed by the joint systems, followed by replacement. MacKinstry (1955) concluded from the description of the pipes by Blanchard (1947) that '. . . it is difficult to explain these pipes as other than the results of corrosion followed by filling and replacement accomplished by fluids (whether liquid or gaseous) originating from the granite and making their way upwards'. Whatever the process, the pipes are unique orebodies in the combination of shape, increase of sulphides with depth, and the clearly evidenced precipitation of wolfram later than molybdenite. In the diagram (Fig. 9) the pipes are tentatively placed in the hypothermal group because of the presence of tourmaline, bismuthinite, topaz, fluorspar, and pyrrhotite, and the greisenous wall-rock alteration.

The deposits south-east of Petford appear to be a mixed collection of hydrothermal tin, wolfram, fluorspar, silver-lead, and copper lodes. They are possibly associated with important north-south fault systems, the existence of which has been inferred from photo-interpretation and stratigraphical considerations.

Among the remaining groups scattered over the area are the Khartoum molybdenum-quartz veins; the Fluorspar gold and fluorite veins; and the Lappa Lappa silver-lead and tin veins north-west of Bamford Hill.

The mica-pegmatite deposits at Mount Kitchin are the only examples of deposits that are not associated with the Permo-Carboniferous granite intrusions. They are an extreme result of the pre-Silurian metamorphic-metasomatic processes and associated pegmatite intrusions in parts of the Dargalong Metamorphics.

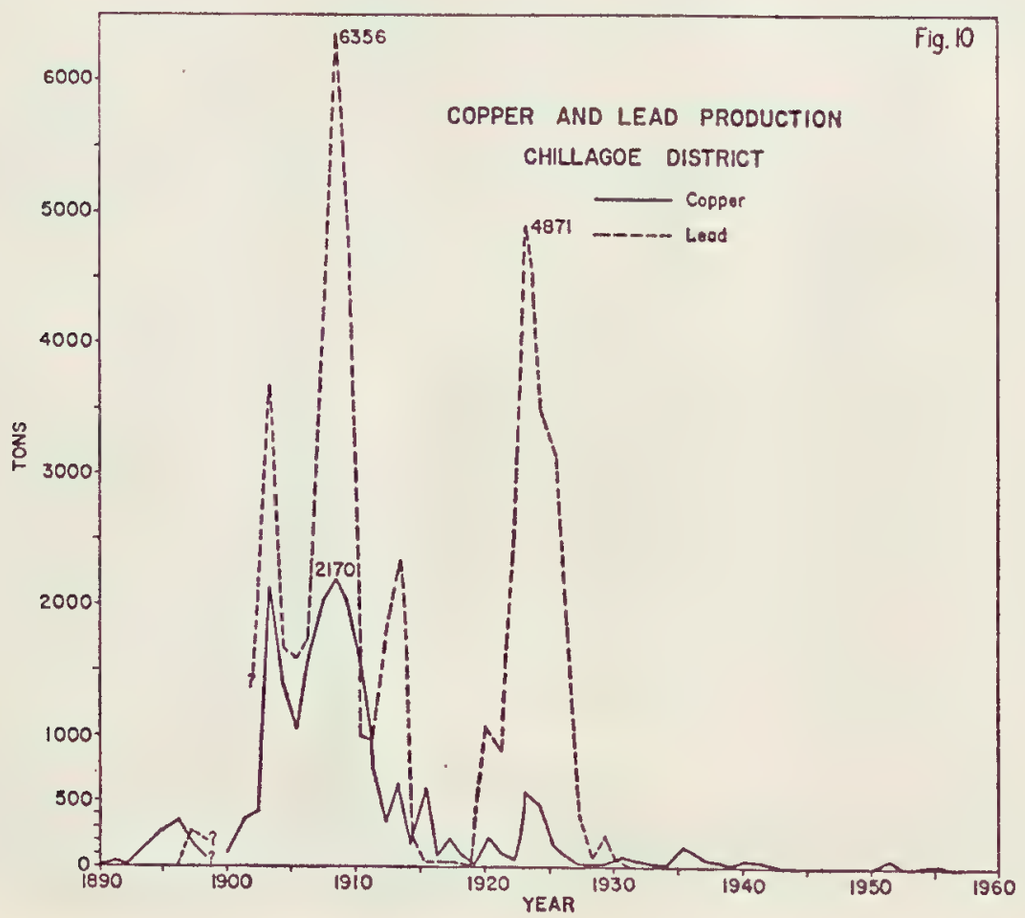
DESCRIPTION OF MINES

In the following pages, bracketed numbers after the names of mines refer to the Mine Locality Index (Appendix 1) and to the Mine Locality Map (Plate 13). All mines located during our field work in 1958 are briefly described, and references are given for further detail. The great majority of the workings have collapsed or are water-filled, and are now inaccessible.

Copper, Lead, Silver, Zinc

The copper and silver-lead deposits in the Chillagoe district have generally been given the most attention throughout the years, though quantitatively their aggregate yield is small compared with that of other mining centres in Australia.

Many of the lodes contained a mixture of lead (silver) and copper minerals in varying proportion, from almost lead-free ore (Ruddygore) to copper-free

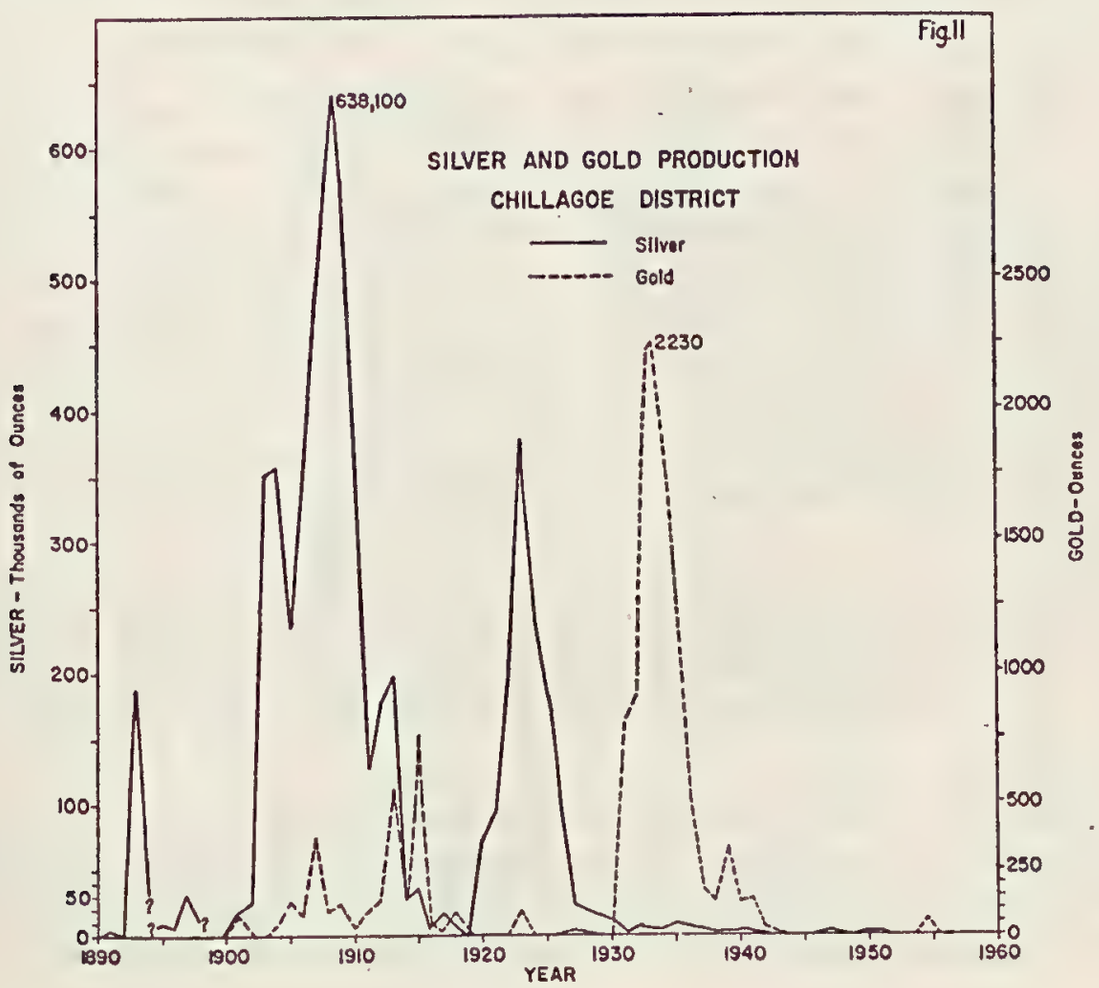


silver-lead ore (Torpey's Crooked Creek). Most of the lead ores carried increasing quantities of sphalerite in depth, and the copper lodes generally contained some bismuth as an impurity. As the smelters could not separate the zinc, large quantities were wasted during treatment.

Initially the grades of ore were high: in 1896, for example, ore from the Harper and from the Lady Jane contained 25 percent copper, from Ruddygore 20 percent copper, and from the Christmas Gift shaft as much as 40 percent copper.

The hundreds of shows and workings in the area are concentrated mainly in the region between Almaden and Mungana-Redcap, and around Cardross. Most of the workings were small, disconnected, and shallow. Greatest production has come from the Mungana lodes, which were responsible for about one-third of the total production of copper, and for two-thirds of the total of lead and silver.

Most of the mines have been fully described by Jensen (1941), after detailed geological mapping of the area by the Aerial, Geological, and Geophysical Survey of North Australia. Individual reports by geologists of the Geological Survey of Queensland have appeared from time to time in official publications. Several private companies, and E. Broadhurst, consulting geologist, investigated most of the important deposits after the war, in particular those in the Redcap and Mungana areas and at Ruddygore. A list of plans and sections of the various workings, kept in the offices of the Geological Survey of Queensland, is given in Appendix 2.



Mungana Area

(Jack, 1891, 1898; Poole, 1922; Jensen, 1920b, 1941; Broadhurst, 1952, 1953)

The Mungana mines are aligned along a zone extending for about 1½ miles from Mungana to the south-east, parallel to the general strike of the sediments, and include the Girofla, Lady Jane, Dorothy, Griffith, Magazine Face, and a number of smaller workings.

Total production has been 31,831 tons of lead, 7907 tons of copper, and 3,228,600 ounces of silver from 333,591 tons of ore (Broadhurst, 1953). The average recovery grades can thus be taken as being 9.6 percent lead, 2.35 percent copper, and 9.7 ounces of silver per ton. The Girofla and the Lady Jane were the outstanding producers.

The lithological units in the Mungana mineralized zone consist of the limestone, quartz greywacke, chert, chert breccia, siltstone, and sandstone of the Chillagoe Formation, and possibly some basalt flows, but the detailed geological picture is complicated by faulting, folding, stratigraphic lensing and tonguing, and extreme alteration in places. Rhyolitic and possibly doleritic dykes also occur.

There is much confusion about the true nature of the lodes and, in particular, about the origin of the pipe-like deposits at the Girofla and Lady Jane mines (see also page 23). Many outcrops are so strongly brecciated, silicified, or altered to soft, clayey material that the original rock type cannot be recognised. Most of the breccias and some of the other rock types are considered by Broadhurst (1952) to be volcanic, whereas Jensen (1920b) regarded them as crush breccias.

Jack (1891) and Skertchly (1897) were convinced that some of the lodes (Griffith, Girofla) were mineralized cave deposits in limestone. Jensen (1920b) originally thought of a south-east-trending fissure lode with a number of mineralized branches dipping into the main fissure and controlled by joints dipping north-east. He revised his opinion somewhat in 1941, after more information had become known, and considered the Mungana belt as a 'fairly wide fractured zone' within which the rocks had been broken into blocks with differing attitudes and had been subjected to considerable minor faulting. Broadhurst (1952, 1953) believed that the lodes occur in a line of breccia-filled volcanic vents or diatremes; during our 1958 survey, however, no proof could be found for this hypothesis, and Jensen's explanation is probably nearest the truth (see also page 23).

Factors that led to the closure of the mines included: excessive influx of water, difficult stoping ground, low grades in the bulk of the ore, fires at the Lady Jane, closure of the Chillagoe smelters, and, naturally, exhaustion of the higher grade ores.

Since 1930 some private companies, smaller syndicates, and the Federal Government have investigated the area geologically, geophysically, and by drilling, in order to re-assess its potential, but results were not sufficiently encouraging to warrant re-opening of any of the mines. In 1930 electric prospecting methods

were employed by the Imperial Geophysical Experimental Survey in the Griffith* area (Broughton Edge & Laby, 1931, pp. 127-134), and four drill holes were put down to depths between 150 and 200 feet. Broken Hill South Ltd investigated the Mungana area geologically from 1947, and in 1948 requested the assistance of the Bureau of Mineral Resources. This was given in the form of a geophysical survey in the Mungana, Redcap, and Zillmanton areas in 1949, during which electromagnetic, magnetic, and self-potential methods were used (Langron, 1957). In the Mungana belt the only electromagnetic indications (and those weak) were confined to the Lady Jane sector, where some well-defined anomalies were due to mineralization or to the presence of a ferruginous clay and 'ironstone' zone: test drill holes on the 1930 anomalies near the Griffith had encountered only such ferruginous clay and ironstone and little or no mineralization.

In 1956 and 1957 the Chillagoe Prospecting Syndicate put down some drill holes on Moffats Hill and on the Griffith Lease.

Girofla (23, a) (Jensen, 1941; CSIRO, 1952; Broadhurst & Edwards, 1953).

The Girofla mine, which lies nearest Mungana on the north-western end of the zone of workings, was the biggest single mine in the Chillagoe district. It has produced an estimated 220,000 tons of ore (Broadhurst & Edwards, 1953), which, judging from the reported average recovery grades, should have yielded 29,600 tons of lead, 5900 tons of copper, and 1,750,000 ounces of silver. The mine was discovered in 1888 and worked until 1914. From 1920 to the closure of the smelters in 1926, the mine was worked by the State Government. Operations started from two or three open cuts, but before long a shaft was sunk which ultimately reached a depth of 823 or 840 feet, and levels were developed at 100, 200, 300, 410, 510, 610, 710, 810 feet.

The lode consists of three vertical pipe-like bodies, two of which cropped out at the surface as siliceous and ferruginous cappings originally called the North Blow and the South Blow (Jack, 1891). These two pipes, which had a diameter of 20 to 30 feet at the surface, broadened at depth, and joined together at about 150 feet. The composite pipe had its maximum diameter of 250 feet at the 410-foot level, but narrowed again to approximately 60 feet farther down. A fourth orebody (North Lode) was discovered in 1921 at the 100-foot level and was worked down to the 400-foot level.

The pipes are filled with chert breccia with a clayey matrix, which was silicified at the surface. The upper three levels yielded mainly flux ore. At 410 feet large quantities of secondarily enriched copper-lead ore were mined, and from the 510-foot level downwards lead sulphide ore was worked.

The mineralization of the Girofla lodes has been described by Broadhurst & Edwards (1953), who report that the primary ore consisted of abundant pyrite, pyrrhotite, and marcasite, lesser amounts of galena, sphalerite, chalcopyrite,

* 'Griffith' in the older references, 'Griffiths' in many of the later ones.

jamesonite, and tetrahedrite, and sparsely distributed arsenopyrite and stannite, in a sideritic gangue. Copper had largely been leached from the upper three levels, but lead had been accumulated in the siliceous ferruginous cappings as cerussite and a lead silicate, with an average grade of 26 percent lead. The average grade of the primary ore was of the order of 0.5 to 1 percent copper, 8 to 15 percent lead, 7 to 10 ounces of silver per ton, and 10 percent zinc.

At about the 410-foot level, strong secondary copper enrichment had taken place, with covellite and chalcocite replacing pyrite; ore from this level assayed 6 to 10 percent copper. The precipitating influence of the limestone wall-rock also caused some copper enrichment on the periphery of the copper-leached ores in the higher levels.

Microscopic work showed that the supergene ores were, in turn, partly oxidized to copper carbonates, cuprite, native copper, and limonite, owing to the downward movement of the groundwater level concomitantly with erosion (Broadhurst & Edwards, 1953). The presence of supergene sulphides at a depth of 400 feet, although groundwater level is only 30 feet below the surface, may be explained by the free water circulation afforded by solution channels in the limestone.

The Girofla is worked out as a copper mine. Possible reserves of lead ore below 800 feet in the pipe-like orebody with relatively small diameter are probably short of the minimum tonnage required for an economical re-opening of the mine, especially as water presents a mining problem at that depth.

Lady Jane (23, b)

The Lady Jane mine, in limestone less than half a mile south-east of the Girofla, was the second-largest producer at Mungana. Mining started in 1899, and the Lady Jane was a very important producer until 1909, when cave-ins and underground fires (caused by spontaneous combustion of the ore) disrupted activities. Attempts to extinguish the fires by flooding did not succeed because the high permeability of the limestone permitted the water to drain away and even to reach the Girofla shaft. The mine was finally re-opened in 1923 and worked by the State Government until 1926.

The total recorded production is reported to be some 102,000 tons of ore averaging 5.3 percent copper, 16.7 percent lead, and 12.2 ounces of silver per ton (Broadhurst, 1953). (But, if these figures are translated into metal, and added to the Girofla figures, the two together exceed the reported total for the Mungana area.)

Four shafts were sunk, the main one reaching a depth of 460 feet, and levels were driven at 60, 100, 150, 210, 290, 320, and 420 feet. The lode had the form of a small pipe at the surface (Jensen, 1941), and, at the 200-foot level, was 200 feet by 67 feet in size, elongated in a general south-easterly direction. The pitch was stated to be steeply to the south-south-west. Connected with the main lode were three smaller ones containing irregular bunches of copper ore.

Broadhurst (1952) described the Lady Jane lodes as being '. . . in the upper funnel-shaped part of a vent, which is elongated along the strike of the line of vents'.

High-grade (10 percent) copper carbonate ore persisted from the upper levels to a depth of about 150 feet, where it changed to good-grade lead sulphide ore veined by high-grade copper and copper-lead carbonate ore. The main lead sulphide orebody at this level carried about 9.8 percent lead, 3 percent copper, and 12 ounces of silver per ton, but owing to the numerous rich copper ore veins, two to four feet thick, throughout the lead ore, the Lady Jane was generally regarded as a copper mine.

Between the 290 and 320-foot levels the ore contained 3 percent copper, 18 percent lead, and 10 ounces of silver per ton, and at 320 feet was enriched in supergene copper sulphides. This high-grade ore, carrying about 13 percent copper, was mined from stopes above the 420-foot level.

Below the 150-foot level it was possible to mine copper and lead from separate stopes in separate operations; in other parts of the mine the ores were mixed and were mined simultaneously.

Other Mines

The other workings in the Mungana area have not contributed much to the total production, and have reached only shallow depths.

The *Dorothy* mine (23, c), about 2000 feet south-east of the Lady Jane, is one of the oldest mines in the Chillagoe field. Mineralization occurs in coarse-grained garnet-calcite rock, but only the enriched surface ore has been mined, the primary ore—at a depth of about 50 feet—being generally below economic grade. Moreover, the lode was much faulted at depth. The old main shaft, now fallen in, started from an open cut and reached a depth of 165 to 200 feet, revealing orebodies at the 50-foot and 100-foot levels averaging 5 percent and 10 percent copper respectively. The ore occurred largely as nodules of azurite and malachite containing some copper oxides, and in the primary zone as disseminated chalcopyrite and bornite. Basalt crops out on the north side of the lode, and contains some veinlets and granules of native copper (CSIRO, 1955b).

Griffiths Hill (23, i), also one of the earliest workings in the field, is about 2400 feet south-east of the Dorothy mine, and comprises an open cut and several small shafts, the deepest of which, Griffith No. 1, went down to 220 feet. The open cut, 300 feet long by 150 feet wide, and about 80 feet deep, was worked for cupriferous iron flux (Jensen, 1940); it appears to lie on a branch (lode) of Jensen's main fissure zone, and strikes 070°. The ore at the surface consisted of nodules of copper carbonates in a siliceous ferruginous breccia, and was locally concentrated into rich pockets near a limestone lens. An intrusive body of quartz porphyry was exposed in the open cut.

The Griffith No. 1 Shaft was connected with the *Calumet* shaft (23, h) by means of a cross-cut driven 538 feet north from the 200-foot level. At the Calumet the ore occurred in bands of ironstone, up to three feet wide, containing nodules of malachite and cuprite.

The *Malachite* lode, 300 feet north-east of the Griffith open cut, and the *Nordville* (23, g), north-west of the Griffith, are two small interconnected workings on probably the same fault, and have yielded a few tons of rich copper ore whose grades ranged up to 15 percent, and, in one parcel, even 49 percent copper.

The Magazine Face open cut (23, f), on an east-west garnetiferous or ferruginous branch of the lode that extends from the Dorothy to Griffiths Hill, yielded ore assaying up to 12 percent copper. The ore consisted mainly of boulders of copper carbonate and chalcopyrite in soft, clayey gangue.

The *Red Dome* (23, e) is a hill south of Magazine Face, and between the Dorothy and the Griffith workings. Mineralization occurs in a jasperized breccia near its contact with a much-weathered porphyry. Many small shafts and costeans have yielded some cupriferous iron flux. Gold values ranging up to 7 dwt per ton were reported from some of the workings.

Many other small workings—e.g., the Hookworm, Moffat's, and Kaolin—yielded small quantities of cupriferous flux ores.

The *Red Hill* (or Ben Nevis?) (14) and the *Jubilee* (13) are small, isolated prospects, one 2½ and the other 4 miles north-west of Mungana, and are located on ironstone lodes in the contact zone around an intrusive microgranite porphyry. Surrounding calcareous sediments have been converted to calc-silicate rocks. The Red Hill shaft was more than 100 feet deep. At the Jubilee, malachite and chrysocolla were noted in ironstone and epidote-rich calc-silicate rock. No records of the production of these workings are available.

Redcap Area

(Morton, 1926b; Jensen, 1941; Broadhurst, 1952.)

The Redcap area (22), though larger than the Mungana area and containing more workings,, has never reached the same prominence in production.

The first lodes were known as early as 1888, and some rich secondary ores near the surface were mined until 1909; in later years the mines produced mainly flux ores. Output figures are very incomplete, as the smelter records did not show the sources of the ores. From what is known, it seems that even the most extensively worked mines—the Penzance, Queenslander, and Morrison—did not produce more than a few thousand tons of ore.

In 1949, geological and geophysical surveys were carried out in the Redcap area as part of the same programme that covered the Mungana area (Langron, 1957) (page 65). Geophysical methods (mainly electrical) were employed on both sides of Mount Redcap, and two sites were recommended to test an

electromagnetic anomaly that might be due to mineralization; the axis of this anomaly trends from the Redcap opencut to the north-west, parallel to the Redcap fault. Drilling was carried out by Broken Hill South Ltd. the next year.

Earlier, in 1930, the Imperial Geophysical Experimental Survey had investigated the Redcap-Morrison line of mineralization by means of equipotential line and A.C. potential ratio methods, but follow-up drilling on recommended sites was soon abandoned because of poor results, and technical difficulties.

The Chillagoe Formation, in which the workings are located, here consists of intertonguing and lensing beds of limestone, calc-silicate rock, chert and chert breccia, basalt, limestone-conglomerate, quartzite, and conglomerate. A well-defined fault, forming the locus of the Redcap lode, separates the sediments from a hilly area of quartz-feldspar porphyry to the north-east. Hornblende-biotite adamellite and granodiorite have intruded both sediments and porphyry, forming calc-silicate rocks, and crop out to the north-west and south-east of the Redcap lodes. The origin of the breccias has been discussed on page 23.

There are several lode systems, the more important of which strike north-west.

The Redcap lode is the largest in the area; it more or less follows the Redcap Fault, and includes the Redcap mine (22, a), the Queenslander (22, b), and the Morrison Shafts (22, c), besides a few smaller workings. The orebodies are on the main fault or on secondary shears parallel to it; they dip about 45° south-west. At its north-western end the lode outcrop is 40 to 60 feet wide in garnet-ironstone, but its width decreases to the south-east; between the Queenslander and the Morrison shafts it is only 10 to 20 feet wide, and about 1000 feet south of the Morrison its place is taken by a chert band sandwiched between limestone and siltstone. The total length of the lode is nearly 7000 feet, and workings extend over about 3000 feet. Some short branches or ironstone take off from the main lode at angles of 45° to 90°. Brecciation is very common, and is particularly well developed at Mount Redcap, which had been regarded as an extinct volcano by Jack (1891), and as a diatreme by Broadhurst (1952). The type of mineralization seems to change from lead in the north-west to copper (mainly) in the south-east.

The *Redcap* mine (Morton, 1926b), probably discovered in 1891, was largely neglected until 1926. The original lease yielded lead ore with high silver values, but the lodes were small and irregular, so that mining remained spasmodic and on a very modest scale. In 1926 the lease was taken over by the State Government; an orebody 230 feet long and with an average width of 50 feet was proved, and a second low-grade orebody, apparently separated from the first by a strip of barren breccia, was found on the north-eastern side of the hill. A tunnel was driven south-east for 220 feet, 185 feet of which were in ore, and an open cut

above the tunnel showed a width of 25 feet of ore. Other workings include a main shaft at least 150 feet deep, and another adit driven for 95 feet north-west.

The average lead content was 6.7 percent, but silver values were surprisingly low, generally considerably less than 1 ounce per ton. Ore reserves, assuming an average vertical extent of 64 feet for the orebody, were estimated at 40,000 tons. In 1926 and 1927, 3535 tons of ore yielded 240 tons of lead and 175 ounces of silver, but the closure of the Chillagoe smelters put an end to all activities. Broken Hill South Ltd included Redcap in their geological exploration programme between 1947 and 1951; more than 1400 feet of drilling showed the orebody to be a shallow structure pitching to the south-east and terminating against underlying porphyry.

The lode material is dark-brown to black, massive, siliceous, ferruginous, and manganiferous, and is commonly brecciated. Cerussite is disseminated through the lode as fine crystals, and a little galena, minium, and massicot were also noted. Pyromorphite occurs in occasional narrow seams, and in manganese-rich portions lead manganate has been reported. An ore sample from the face of the main tunnel at 125 feet assayed (Morton, 1926b): 12.6% Pb, 0.1 oz./ton Ag, 36.4% FeO, 15.0% MnO, 0.5% Zn0, and 11.0% insoluble.

The *Queenslander* (22,b), about 1000 feet south-east of Mount Redcap, was apparently worked for both copper and lead, but very little information is available, and the mine was closed in 1903. As usual the first tonnages were rich surface ores, whereas later yield consisted of flux ores. The mine had several shafts, now caved in. The main or Queenslander shaft was probably more than 200 feet deep, and had levels at 100, 117, and 200 feet. The ore from this shaft consisted of low-grade sulphides containing 1 to 2 percent copper; the No. 1 shaft traversed massive pyritic ore assaying 1 percent copper and 1 ounce of silver per ton, and containing small amounts of galena. From the bottom level of the Queenslander shaft the footwall was explored by a crosscut 600 feet to the south-east. Drilling to a depth of 700 feet revealed sulphides of zinc and other metals in garnet rock; the copper content of the ore ranged up to 1.5 percent. Galena, cerussite, sphalerite, and copper carbonates were noted in the dumps.

The original workings at the *Morrison* (22, c), some 2000 feet south-east of the Queenslander, were known as the 'Queenslander lead shaft', but were worked for copper after they were re-opened in 1899 by Chillagoe Railways and Mines Ltd. The mine was renamed the Morrison in 1905, and an orebody 440 feet long was proved to a depth of 120 feet, partly by drilling. Some 2000 tons of secondarily enriched ore were taken out below this level in 1908. Values at the 180-foot level ranged between 1 and 2 percent copper, but were somewhat higher at the 250-foot level. The deepest level was at 350 feet. The lode narrowed from about 15 feet at the surface to about 3 feet in depth; the footwall was a silicified schist or chert, and the hangingwall was limestone. By the time the mine closed down in 1909 the lode had been explored over a length of 700 feet.

The Penzance-McIlwraith lode system, one half to three-quarters of a mile south-west of the Redcap-Morrison line, follows another relatively important shear-zone. The system consists of two parallel lodes, six to eight feet wide and 120 to 150 feet apart, extending over three-quarters of a mile and striking south-east. The main, or western, lode dips 70° north-east, and contains the *Puppet* (22, e), *Cambourne* (22, f), and *Penzance* (22, g) workings; the eastern lode dips steeply to the south-west and contains the *McIlwraith* mine (22, g). The lodes occur in limestone, and are separated by fine-grained cherty basalt; garnet and ironstone replacements form the bulk of the intervening material in the Penzance-McIlwraith area. The mines were mainly worked for copper, though some lead ore was present, and a little cobalt was also found.

The *Penzance* and *McIlwraith* workings (22, g) are close together, and are connected by a crosscut at the 150-foot level. Their main shafts have been obliterated by three large open cuts: the Penzance (330 feet long, 100 feet wide, 100 feet deep), the McIlwraith, and the Magazine. The Penzance was one of the first mines opened in the Chillagoe district: in 1888 a lode, 400 feet long and 80 feet wide, was reported to have contained up to 40 percent and even 75 per-cent copper. The first yields came from carbonate ore with an average content of 4.5 percent copper and 4.5 ounces of silver per ton. Later flux sulphide ore assayed about 2 percent copper and 2 ounces of silver per ton. The deepest shaft went down to 200 feet. The McIlwraith lode was smaller and of lower grade than the Penzance, and had a main shaft 250 feet deep.

The *Cambourne* (22, f) contained a number of shafts, the deepest of which was 150 feet, and is better known for its cobalt mineralization (see page 117).

Other, smaller, workings on this lode system were the *President* or *Puppet* (22, c), the *Nellie* (22, h), and the *Belgravia.*

The Victoria lode (22, d) is a branch of the Redcap lode and dips 60° to the west (Jensen, 1941). It strikes north-south over a distance of 600 feet, and contains the *Victoria,* the *Tarantula* (perhaps originally spelt 'Triantular), and *Boulder* workings. The footwall is limestone and the hangingwall chert breccia. The mines were worked for either copper or lead in different sections. Frank-linite associated with sphalerite was recorded from the Victoria.

Jensen (1941) mentioned another small lode—the West Victoria lode—on the western bank of Redcap Creek and west of the Redcape lode. Numerous shallow shafts and pits are aligned over half a mile on a gossan line 10 feet wide in this locality.

Ruddygore (25)

(Jensen, 1941; Broadhurst, 1949; Branch, 1960)

The *Ruddygore* orebody, situated two miles north-east of Chillagoe within a metasomatized granodiorite differentiate of the Almaden Granite, differs from all other copper lodes in the district: it is a disseminated, low-grade deposit of

the so-called 'porphyry-copper' type. This was not recognised by the earliest investigators; both Skertchly and Jack, for instance, described the orebody as being in a porphyry dyke cutting the granite.

The workings include two open cuts and four shafts, the deepest of which reached 350 feet. Drives or levels existed at 100, 125, 225, and 325 feet, but production was confined to the 125-foot level and above. The largest open cut was 450 feet long and 80 feet wide, and in 1908 reached a maximum depth of 130 feet. Numerous small shafts and pits were found about 1000 feet south-east of the main Ruddygore workings.

From 1896 to its closure in 1909 the mine produced about 32,750 tons of handpicked ore for a yield of 1450 tons of copper. With the exception of the first 1100 tons of rich ore, the average grade of mined material was estimated at 1.5 percent copper, but the ore produced was handpicked to a grade of about 3.9 percent copper. The production figures again are incomplete, as they were often included in the aggregate smelter returns.

Three diamond drill holes were put down in 1907; one of them, extending 304 feet from the bottom of the No. 1 Open Cut, assayed 13.8 percent copper and 1.6 ounce of silver per ton over a three-foot length of core, probably from the enriched zone near the 100-foot level. From 1947 to 1949 Broken Hill South Ltd put down eight churn drill holes into various parts of the main metasomatized orebody, and three holes into a supposed extension, to depths between 8 feet and 60 feet. Copper values in these holes were generally less than 0.15 percent, the highest assay being 1.33 percent copper in a five-foot section. Mount Isa Mines Ltd put down nine diamond drill holes in the same general area in 1960. These holes were drilled to depths of between 170 and 304 feet. Six holes contained trace values only of copper mineralization. Values in the other three holes were: 36 feet of 1.25 percent Cu, 41 feet of 0.38 percent Cu, 38.5 feet of 0.41 percent Cu.

In 1959 the Bureau of Mineral Resources carried out a geophysical survey of the mine area (Horvath, 1959), which at the same time was mapped in detail (Branch, 1960) in order to aid the interpretation of the geophysical results. The following year W. B. Dallwitz and W. R. Morgan, of the Bureau of Mineral Resources, searching for evidence of other possible deposits of the Ruddygore type in the surroundings, outlined several bodies of highly leached ferruginous metasomatized granodiorite. The largest body of metasomatized rock found was estimated to contain about 500,000 tons per vertical foot, but only sub-surface testing can show whether economic mineralization exists in these bodies.

Branch (1960) recognised five varieties of granitoid rocks in the Ruddygore area, as determined by the relative proportions of quartz, hornblende, and biotite; their boundaries are gradational. They are intruded by leucocratic microgranodiorite (Broadhurst's 'aplite'), which has been considered to be the cause of metasomatism of part of the granodiorite and ultimately of its mineralization.

The mine is situated at the northern end of the largest mass of metasomatized granodiorite, which trends 335°, and crops out over a length of 1800 feet and a width of 400 feet. The degree of metasomatism increases towards the centre of the body. First signs are an alteration of the mafic minerals to epidote and chlorite, leading to an aggregation of bleached chlorite in fibrous clusters. The feldspars become cloudy, and orthoclase and some of the plagioclase are finally replaced by massive sericite.

The trends of the metasomatized zones follow the main vertical joint directions in the granodiorites (065° and 335°); a third, nearly horizontal, joint system is confined to the metasomatized areas, and was considered by Broadhurst (1949) to be one of the main controls of ore deposition.

The orebody is associated with stockworks, breccias, or areas characterized by a network of fine cracks that are the result of shattering of the rock around the microgranodiorite intrusion, either because of mineralization stoping, as advocated by Broadhurst, or because of active upward pushing by the micro-granodiorite, as suggested by Branch. Broadhurst describes the texture of the ore deposits as ' . . . a system of anastomosing quartz veinlets averaging 2 inches, and up to 6 inches, wide, forming a network with a mesh of 2 or 3 feet.' Jensen (1941) stated that the ore occurred as nodular segregation masses, ranging from many feet in diameter to minute specks.

Except for the generally leached surface, the upper 40 feet of the deposit contained mainly copper carbonates, changing to chalcopyritic ore at greater depth. The richest ore, bulking 5 percent copper in places, was found in an underhand stope below the 100-foot level, where chalcopyrite was accompanied by probable bornite, and where secondary enrichment is thought to have taken place. These relatively rich ores terminated just above the 125-foot level, and at greater depth only very low values were found.

Zillmanton (24).

(Jensen, 1941; Branch, 1960.)

The *Zillmanton-Shannon* copper lode, from 2½ to 4 miles west of Chillagoe along the Chillagoe-Mungana railway line (Pl. 14), is the most persistent single lode in the Chillagoe district, and seems to occupy a faulted contact zone between Almaden Granite on the north and limestone to the south. The main workings were in the 3000-foot long eastern or Zillmanton part of the lode. In the 500-foot western or Shannon part, which has been displaced by step-faulting over a total distance of about 1000 feet to the south of the Zillmanton section, only shallow shafts were sunk and these have contributed little ore.

Work started in 1899, and during the years 1903 and 1904 Zillmanton was the largest mine in the district. Production figures again are not precisely known, as the output record was included in the Chillagoe Smelter's returns for the whole district, but the total figure is thought to have been in the vicinity of

35,000 tons of ore with an average grade of 4 percent copper. In 1910, 97 tons of copper and 3200 ounces of silver were obtained from 2253 tons of ore, and in 1911 the production consisted of 250 tons of copper and 8706 ounces of silver from 6306 tons of ore. Many difficulties arose from the soft, clayey nature of the ground (which allowed the shafts to warp under pressure)' and from the tremendous influx of water: pumping at a rate of 1,500,000 gallons per day in 1908, for instance, had very little effect, and the workings were frequently flooded. These difficulties on top of low metal prices and the lack of capital (the available money was spent on newly discovered mines outside the district) finally led to the closure of the mine in 1912, although according to reports some 25,000 to 30,000 tons of proved ore with a grade of 4 to 5 percent copper were still at hand.

Since 1913 a number of mining companies have held Authorities to Prospect over the area, but no development has been attempted. The Bureau of Mineral Resources carried out a geophysical survey over the Shannon lode in 1949 (Langron, 1957), and, combined with detailed geological mapping, over the Zillmanton section in 1959 (Branch, 1960). Of the methods employed only the electromagnetic readings indicated well-defined and, in places, strong anomalies, one of which coincides approximately with the inferred granite-limestone contact, another with a line of lode outcrops (Pl. 14). The axes of the anomalies probably indicate steeply-dipping shear zones made conductive either by their content of mineralized water, or by sulphide mineralization and magnetite. The anomalies extend for more than 8000 feet, in part over alluvium-covered areas where little prospecting has been done; testing by drilling is consequently warranted.

The lode, which strikes east-west and dips 55° to 70° to the south, can be traced for about a mile as a line of siliceous-ferruginous outcrops ranging in width from 20 to 60 feet, though the spread of rubble is much wider. A surface crust of travertine is in many places associated with the ferruginous rubble, and is possibly a residual from the weathering of a calcite-garnet-magnetite rock similar to that found in pits west of the Zillmanton area (Branch, 1960). The lode runs parallel with, and close to, the granite-limestone contact. In depth the lode is mainly a brecciated, siliceous garnet-hematite mixture with a troublesome hangingwall of soft clay or pug 30 to 100 feet wide, and a footwall in kaolinized granite. The best values Jensen stated to have been associated with the kaolinized footwall; the hangingwall carried scattered nodules of secondary copper minerals. In the underground workings the lode was intersected in several places by dykes or tongues of granite. The upper 100 to 200 feet of the lode contained mainly carbonate ore, and in the deeper levels the ore was predominately chalcopyritic.

In the Zillmanton section two main orebodies were opened up: a western body, about 140 feet long and 4 to 6 feet wide, worked by the Reid shaft; and an eastern body, about 270 feet long and 6 to 18 feet wide, and worked by the No. 1 and No. 2 Shafts. The Reid Shaft reached a depth of 376 feet, and bot-

tomed in unpayable ore. It had drives at 200 and 300 feet. The No. 1 and No. 2 Shafts were both sunk to a depth of 350 feet, and levels were established at 100, 160, 250, and 350 feet. The shafts were connected via the 160 and 250-foot levels. When the mine closed in 1912 some 25,000 to 30,000 tons of proved ore assaying 4 to 5 percent were said to remain in the lower levels, and according to Jensen (1941) the grade improved in places on the bottom level.

Calcifer Area (27)

(Jensen, 1941)

The Calcifer group of mines, situated about 5½ miles south-east of Chillagoe, includes the Boomerang, Hobson, Harper, and Five Chain Bend workings, and was one of the first groups opened up in the Chillagoe field. By 1894, when the Calcifer smelters were opened by the Irvinebank Mining Company, the company had in the Boomerang Mine one of the district's main ore suppliers. The mines were first worked for some rich carbonate ore at the surface, but later, when the grades fell to 1 and 2 percent copper, only flux ore for the Chillagoe smelters was produced. From Warden's Reports and other sources a total production from the group of 26,450 tons of ore has been inferred, for a yield of 1555 tons of copper, 20,400 ounces of silver, and about 44 tons of lead-silver bullion.

The lodes are contact-metasomatic deposits in roof-pendants of the Chillagoe Formation within, and irregularly intruded by, the Permo-Carboniferous hornblende-biotite adamellite and granodiorite. The sediments are transformed into marble, chert, hematite/magnetite and garnet rocks, and quartzite. Much of the first production came from a surface accumulation of hematite-quartz boulders rich in cuprite, native copper, and carbonate.

The *Boomerang* (27, c) was worked in a 300-foot wide contact zone, dipping 45° south-south-west, at the junction of the granodiorite on the north and an embayment of altered limestone on the south. The lode-material was generally a garnet rock (Skertchley's 'eclogite', 1897) grading into siliceous hematite-magnetite rock containing veins and nodules of copper ore and, in places, stringers of cerussite. Large quantities of flux ore, with grades ranging from 1 percent to 4 percent copper, were supplied from this mine. Workings included open cuts, the largest of which was reported to have been 300 feet by 240 feet by 70 feet deep, and several shafts and pits.

The *Hobson* lode (27, d) lies about three-quarters of a mile east-north-east of the Boomerang and consists of garnet rock, siliceous ironstone, and much magnetite. Granite is exposed in an open cut 170 feet long, 80 wide, and 60 feet deep; its contact dips about 30° to the north-east. A shaft close to the open cut entered granite at the 100-foot level; an easterly drive at the 150-foot level first penetrated 30 feet of chalcopyritic ore at the contact zone, and then

passed through magnetite, which gradually gave way to garnet rock before the limestone was entered.

The main *Harper* workings (27, f) are situated about 3300 feet east-south-east of the Hobson on what may be described as a faulted contact lode with a north-south strike and a dip of 55° to the west. Granite is exposed on the eastern side, and altered limestone on the western side of the lode, which is about 1½ miles long and generally brecciated. Numerous workings are aligned on the lode; the most important are several shafts 200 and 300 feet deep, and an open cut 160 feet long, 85 feet wide, and about 90 feet deep.

Levels in the shafts at depths of 110, 150, and 200 feet passed through more than 100 feet of lode material containing ore nodules consisting principally of malachite, cuprite, and chalcopyrite in an envelope of ferruginous clay, kaolin, and ironstone.

Broadhurst (1953) described the Harper as being situated in a tongue of tuffs and volcanic breccias, with a synclinal structure that was 'probably formed in association with a volcanic vent'. Jensen (1941) considers that the Harper structure is a down-thrown wedge of contact rocks. We are inclined to the same view on the grounds of photo-interpretation and the presence of a wedge of Featherbed Volcanics, which can be explained in this way without having to resort to the concept of a volcanic vent.

At the northern end of the Harper lode is the *Five Chain Bend* mine (27, e), which had three shafts. The ore was contained in a garnet-calcite gangue.

Chillagoe Group

(Jensen, 1920a, 1941)

Scattered around Chillagoe, and particularly in the area south-east of the township, are many workings and copper and lead prospects. They occur in the limestone and calc-silicate rocks of the Chillagoe Formation at or near their contact with the Permo-Carboniferous hornblende-biotite granodiorite intrusions that crop out extensively to the east and south of Chillagoe. Most of the deposits are of the contact-metasomatic type; some appear to be fissure lodes or faulted contact-metasomatic deposits. Among the more important mines are the Chillagoe Consols, Atherton, Christmas Gift, Lyonite Hills, Otho line, Little Hensey, Big Hensey, Fortunata, and Ti-tree.

The *Chillagoe Consols* (26, a), half a mile north-west of Chillagoe, was an important lead producer in the district, second only to Mungana mines. Output figures (incomplete) show a total of 30,500 tons of ore won during the period 1903-1926 for a yield of 450,000 ounces of silver and 6500 tons of lead. Peak periods of production were 1903, 1906-1909, and 1922-1923. By 1923 most ore above the 118-foot level was worked out, and winzing and drilling failed to

intersect further shoots. After 1923 all production came from isolated and small rich veins that remained to be mined above water-level.

Workings included an open cut and several shafts. The open cut was approximately 175 feet long, 75 feet wide, and 70 feet deep; the main shaft was sunk to a depth of 145 feet. The mine suffered repeatedly from copious influxes of water.

The deposit was probably a fissure lode striking north-west and dipping to the south-west, and was exposed at the surface as porous ferruginous outcrops, gossanous in places and containing cerussite and galena. Both hangingwall and footwall consisted of limestone. One of the main orebodies was 80 feet long and 15 feet wide, and was worked to a depth of 80 feet; it carried 29 percent lead and 18 ounces of silver per ton. Other rich ore shoots are reported to have contained between 15 percent and 48 percent lead, and from about 20 to 35 ounces of silver per ton. The average grade of all ore was about 20 percent lead and 15 ounces of silver per ton. Below 70 feet sphalerite became increasingly abundant.

The *Atherton* (26, c) lode, 1½ miles south-east of Chillagoe, strikes west-north-west, and was only 300 feet long. The lode is said to be in a shear which may pass into a contact lode at depth (Jensen, 1941). Granodiorite probably occurs at shallow depth in the workings—some was found on the dumps. Limestone crops out on the north side, chert breccia on the south side of the lode.

A few hundred yards to the north-east of the Atherton is the *Christmas Gift* (26, d), a sinuous north-dipping iron-garnet lode on the boundary between Permo-Carboniferous granite and recrystallized limestone and calc-silicate rock. Farther to the north-east in the same contact-zone are the workings of the *Lyonite Hills* (26, e): these are remnants of a roof-pendant in the granite and consist of brecciated iron-garnet deposits in recrystallized limestone. The Christmas Gift/Lyonite Hills zone has been prospected by means of numerous shallow shafts, adits, and open cuts to a depth of 90 feet. The lode outcrops are diverse: some parts are very siliceous and high in silver content; others are manganiferous or sideritic; some are cupriferous garnet rocks; others are ferruginous and carry lead. Mineralization is patchy—the output came in small parcels of either high-grade lead ore or high-grade copper ore. One parcel is stated to have given 4000 ounces of silver. About 8500 tons of ore won from the Christmas Gift, between 1910 and 1927, yielded 27,700 ounces of silver, 500 tons of lead, and 85 tons of copper. Rich sphaleritic ore with up to 40 percent zinc existed but was disregarded for lack of demand and smelting facilities.

In one of the Lyonite Hills lodes a new lead mineral was first discovered: Chillagite (or Lyonite). It is a yellow to brownish molybdo-tungstate of lead with the formula $3PbWO_4$, $PbMoO_4$.

The *Otho* line of lode is a 50 to 300-foot wide garnetiferous belt running from a point half a mile east of the Chillagoe railway station in a south-easterly

direction about two miles along the contact between limestone and granite. The lode is composed of garnet, hematite, and jasper. Workings are concentrated mainly in the north-western part of the lode and consist of numerous fallen-in shafts. No production figures are known, but silver and lead were the main metals produced. Jensen (1941) found a copious growth of the 'copper-plant' (*Polycarpea spirostylus*) from the central and south-eastern sectors, and he recommended diamond-drill testing of these areas as copper prospects.

The two Hensey lodes crop out between two and three miles to the south-east of Chillagoe. The *Little Hensey* (or *Upper Hensey*) line (26, h) is a contact-fissure lode in rough limestone country. The lode strikes north-west or west-north-west, dips steeply south-west, and is composed of quartz, jasper, and garnet. A tongue of granite intrudes the limestone near the southern extension of the lode. Workings extend for some 500 feet along a zone 5 feet wide, and include several shafts and an open cut. The greatest depth reached was 300 feet. The ore was bunchy and yielded lead, silver, and some copper. No production figures are known, but it is reported that ore won during the early part of the century assayed about 18 percent lead, 6 percent copper, and 17 ounces of silver per ton.

The *Big Hensey* (or *Lower Hensey*) line (26, i and j) is less than half a mile east of the Little Hensey and runs parallel to it. The lode, which is exposed for two miles along the granite-limestone contact near the Chillagoe-Almaden road, dips steeply south-west, and consists of a brecciated ferruginous quartz-jasper-garnet mixture; its southern part follows the curved contact to the *Fortunata* shafts (26, k), where the lode is widest and contains much garnet and vesuvianite.

Silver-lead and copper ore was won from a great number of shafts, mostly from the 75-foot level. Very little information is available on production figures.

The *Ti-tree* (26, g) is a large but low-grade copper deposit 2½ miles south-east of Chillagoe. Mineralization shows on three low hills, the centre one of which contains the main lode, exposed over a length of 1500 feet on the south-western edge of a roof-pendant in Permo-Carboniferous granite, striking north-north-west and dipping 40° to 60° east-north-east. It is a true contact-metasomatic deposit, with granite near the footwall and a garnet-limestone rock as hangingwall. The lode material is jaspery hematite-magnetite-garnet rock with 1 to 3 percent copper minerals. The garnet in places is very coarse and ranges up to 5 inches across. Large quantities of flux ore were supplied to the Chillagoe smelters, but the quality was poor owing to the predominance of garnet. The average recovery grade was 1 percent copper and 0.6 dwt of gold per ton; chemically the ore had an average composition of 31 percent SiO_2, 33.5 percent FeO, and 25.5 percent CaO. In 1941 Jensen estimated that 350,000 tons of flux ore were available, containing at least 3500 tons of copper.

Drilling in 1906-1907 revealed the occurrence of garnetiferous rock of variable thickness to a depth of 433 feet. One hole intersected a true thickness

of 20 feet of garnet rock, the richest 5 feet of which assayed 2.9 percent copper, 0.6 dwt gold per ton, and 1.2 ounces of silver per ton.

Workings on the main lode include an open cut, measuring 200 feet by 60 feet by 40 feet deep, and several shafts, one of which reached primary ore. Production during the period 1923-1942 totalled 32,800 tons of ore for a yield of 400 tons of copper, 18,800 ounces of silver, and 1760 ounces of gold.

Muldiva Mines (35)

(Ball, 1914a; Jensen, 1923)

The Muldiva silver-lead and zinc mines are situated about 8 miles west-south-west of Almaden, on the north side of the Almaden-Tate road. Muldiva was one of the first mining centres opened up in the Chillagoe district: a smelter had been erected by 1891, but was dismantled in 1893 owing to a drop in metal prices. The mines were worked intermittently and on a small scale between 1893 and 1912, after which the Chillagoe Company Ltd acquired the leases and continued operations. The main period of production appears to have been 1909-1914; from 1917 to 1926 there was intermittent activity and moderate output until the closure of the Chillagoe smelters in 1927.

Total returns up to the end of 1926, compiled from Warden's Reports, amounted to about 19,000 tons of ore, yielding 315,000 ounces of silver, 1150 tons of lead, and 270 tons of copper. Apart from a few tons in 1924 and 1926 no zinc production was recorded, no doubt because of lack of demand.

In 1955 five diamond drill holes were put down by Metals Exploration Ltd to depths of 350, 156, 120, and 192 feet; assay values of intersected lode material were low.

The lodes appear to be contact deposits, in limestone and chert of the Chillagoe Formation, which are metamorphosed by Perma-Carboniferous adamellites cropping out in the immediate vicinity to the north, west, and south. Some of the calc-silicate minerals formed are garnet, wollastonite, actinolite, diopside, and epidote. Workings include the Eclipse, Paisley, New Moon, and Li-moon (or Ly-ee-moon), which occur in that order over a stretch of half a mile from the Almaden-Tate road north-west to the northern granite body. Known orebodies appear to be largely worked out, and further ore-shoots could be expected only at depth.

In general, the proportion of zinc in the ore increases with depth. Small quantities of bismuth in several of the ore-shoots spoiled the market value of the silver-lead ore, particularly in the Paisley mine. Cerussite and anglesite were the common ore minerals in the oxidized zone.

The *Eclipse* mine (35, a) occurs in a rock composed of garnet, calc-silicates, and brecciated quartz-hematite on a hill slope at the contact of granite (southern side of the hill, near the base) and metamorphosed limestone and calcarenite

(top of the hill). Malachite, azurite, chrysocolla, galena, sphalerite, and pyrite are among the minerals found on the old dumps.

Two adits have been driven at heights 80 feet and 60 feet from the top of the hill, one in the direction of strike, the second across the strike. Other workings include two shafts, 60 and 80 feet deep, a winze to a depth of 165 feet, and an open cut 90 feet by 60 feet by 50 feet deep. Warden's Reports in 1926 mentioned the presence of an orebody 70 feet wide, 80 feet long, and 40 feet in depth, exposed in a winze from the top adit; it was stated that 10,000 tons of ore assaying 25 percent zinc were developed; for some reason, however, these 'did not break up to export requirements'.

The *Paisley* mine (35, b), about one quarter of a mile north-west of the Eclipse, is situated on a hill in metamorphosed limestone, calcarenite, and chert. The ore minerals occur in a garnet-calcite gangue; with increasing depth the association becomes pyritic and siliceous. One of the main workings was an open cut 170 feet by 120 feet by 50 feet deep, with a 160-foot deep shaft in the centre. Among the other workings are smaller open cuts, many shafts and prospect holes, and the Linedale Tunnel, which had a length of 300 feet. Rich silver-lead ores were taken out, in particular from the main open cut, but some of the output was rejected by the smelters because of the bismuth it contained.

An assay plan for 1914 shows values of 11.45 ounces of silver per ton, 13.95 percent lead, and 2.72 percent copper, over a length of 130 feet and a width of about 5 feet at the 150-foot level.

After the Paisley was taken over by the State Government in 1921 a new shaft was sunk to 150 feet; from then on there was intermittent activity until the Chillagoe smelters closed in 1927.

The *New Moon* orebody lies on the granite contact north of the Paisley and dips steeply to the south.

The *Li-moon* orebody, situated in the granite some 110 yards north of the Paisley, strikes east-west, and has a clayey gangue containing disseminated sulphide ore rich in silver but unfortunately also with a high bismuth content.

Cardross Area

(Ball, 1917a, 1918a)

The Cardross group of mines lies 20 miles west-north-west of Mungana, on the south side of the Mungana-Blackdown road. Originally known as the Klondyke or Bedford, the centre was called Arbouin before finally being designated as the Cardross group. Both Arbouin and Cardross were small settlements during the heyday of the area.

By far the most important workings were grouped on the so-called L-line (5) in a north-north-east-striking zone about 2 miles long and 1/3 mile wide.

Other workings sometimes included in the Cardross group are the Spaniard (6) and the Mountain Maid (7), respectively 4 and 6 miles south of Cardross; the Noonday leases to the south-west (not located during the 1958 field season); and numerous other small and scattered workings to the east and north.

The first leases were taken up in 1898 by Linedale's West Chillagoe Coy Ltd, which was merged with the Irvinebank Mining Co. in 1904. In 1907 this company withdraw from the field, and was succeeded by the Scottish North Queensland Exploration Co., which went into liquidation in 1911. Its leases were transferred to the Mammoth Copper Mine Ltd, a company floated in 1907. A copper blast furnace was installed at Cardross in 1912, and by 1915 mining had reached its peak with a production of 591 tons of copper, 769 ounces of gold, and 29,179 ounces of silver from 8090 tons of ore. After this, owing to difficulties imposed by World War I, production rapidly declined and within a few years the mines had all closed down. No figures are available for the years after 1918. The smelter, which had been in use for only a few short periods, was sold for removal in 1921. Several attempts to re-open some of the mines were made in later years, and a few tons of ore were won from 1932 to 1934.

The total recorded production has been of the order of 18,000 tons of ore for a yield of 2000 tons of copper, 2200 ounces of gold, and 87,200 ounces of silver. Very few figures are known for the early period up to 1909, because they were included in the total output for the Chillagoe district.

The lodes are distinguished from the rest of the Chillagoe copper deposits because they were emplaced in the gneiss and schist of the Dargalong Metamorphics, and are described by Ball (1917a, 1918a) as '. . . very irregular composite fissure systems . . . with the commercially valuable ores occurring bunched at intervals in an enmeshed series of fissures'. Particularly in the main area, or L-zone, the lodes form a network of intersecting veins and shears which generally dip to the west. In places the fissures are clean-cut and have fresh wall-rocks, but more commonly the lodes consist of sheared and altered zones which locally contain rich ore-shoots. The alteration consists of kaolinization, the formation of muscovite, and silicification—partly in the form of quartz-veining. Ferruginous caps are normally lacking on the surface outcrops, and gossans are rare: Ball considered that '. . . it is doubtful if, but for the relatively high gold values, any sinking would have been done on the formations'. The relative paucity of iron in the deposits, compared with the lodes in the limestone country of the Chillagoe-Mungana area, was considered a disadvantage because it made the Cardross ores unsuited for use as flux ore. Another disadvantage of the Cardross area was its remoteness from the railway and the limestone quarries.

The longest ore-shoots were those of the Chieftain (600 feet by 6 feet), Clansman (200 feet by 3 feet), and Spaniard (200 feet by 2 feet); they seem generally to pitch flatly southwards. Pyrite, chalcopyrite, much arsenopyrite, and magnetite, in various proportions, are the common primary metallic minerals. The gold content of the Cardross ores has been relatively high, with values reach-

ing half an ounce or even 1 ounce of gold per ton, and was actually the decisive factor when the sinking of a shaft was being considered. The total yield of 2200 ounces of gold (recorded) is of the same order as the yield from the Mount Wandoo gold mines. Galena and sphalerite were found in only a few mines (notably the Caledonia). Small quantities of wolframite, cassiterite, and traces of bismuth and molybdenite have also been recorded, particularly from the Baker's Camp lodes (not located during the 1958 survey). The presence of such minerals as magnetite, tourmaline, wolframite, and locally some cassiterite and topaz, suggest deposition under generally high temperatures.

Owing to the absence of carbonate rocks, a rich zone of secondary enrichment could form at groundwater level and below, at various depths between 50 and 160 feet. Copper minerals from this zone include chalcocite, covellite, chalcopyrite, and bornite, and grades ranged from 8 to 20 percent copper, and even exceeded 30 percent.

The primary sulphide zone did not contain more than an average of 6 or 7 percent copper. In the leached and oxidized upper 100 feet of the lodes and at the surface the principal copper minerals were the carbonates malachite and azurite, and the copper arsenates scorodite (essentially an iron arsenate) and olivenite; cuprite has also been recorded.

Among the 60 leases or so in the L-zone, the most important was the Chieftain, followed by the Caledonia, Clansman, Keppoch, Albin Macgregor or Allan, Klondyke, and Lochinvar.

The *Chieftain* (5, a) — or Macao in the early days — was by far the best producer, and is reported to have contributed 95 percent of the total yield of the Mammoth Copper Mine Ltd—the operating company for the longest and most active period in the mine's history. Its main shaft went down to 373 feet, and levels were developed at 110, 131, 160, 225, and 305 feet. The largest lode, 600 feet long, had an average width of 6 feet. Only low copper values were found in the upper 100 feet of the leached zone, but the enriched ore at greater depth contained from 10 to 30 percent copper. However, the rich shoots appear to have been exhausted.

The *Clansman* (5, e)—originally known as the Lamington— had a main shaft of 200 feet deep, two other shafts, and a number of open cuts. Levels were put in at depths of 22 feet, 45 feet, 80 feet, and 125 feet. Ore from the Clansman was especially rich in gold, and also contained wolframite. At the 125-foot level the lode was 2 feet wide and assayed 20 percent copper, 15 dwt of gold, and 10 ounces of silver per ton over a length of 80 feet.

Workings at the *Caledonia* (5, c) at Klondyke Creek comprised a number of shafts 40 to 75 feet deep, and yielded chalcopyritic ore with pyrite, sphalerite, and some galena. A typical sample of oxidized ore assayed 2.5 percent copper, 10.8 ounces of silver per ton, 9 dwt of gold per ton, and 36.0 percent iron. A sample of sulphide ore contained 9.6 percent copper, 2.9 ounces of silver and

1 dwt of gold per ton, 18.5 percent iron, 36.0 percent silica, and 15.0 percent aluminium oxide. Diamond drill holes on the lease appear to have struck ore containing 15 percent copper at a depth of 150 feet in one place, and 'dense sulphide ore' at a second locality, also at 150 feet. A third drillhole struck 5 feet of 20 percent ore (Ball, 1918, a).

The *Albin Macgregor* or *Allan* leases (not located in 1958) adjoin the Chieftain lease along their northern boundaries. Workings include shafts with a depth of at least 200 feet, and levels at 55, 70, 100, and 166 feet. The ore produced showed copper values between 8 and 27 percent (the latter percentage from enriched ore), and the last assay rcorded, from 198 feet depth, gave a result of 8 percent copper over a width of 8 inches.

Although the assay values quoted above, and others mentioned in Ball's report, seem attractively high, it must be pointed out that, according to Ball (1918a, page 18): '. . . the ore deposits of Cardross are on the whole neither very high grade nor of very great size. Rich ore-shoots seldom crop out at the surface, and the few found have not been of startling magnitude.' The width of these rich ore-shoots is rarely more than two or three feet and their length is generally of the order of several tens of feet, lengths of a hundred feet or more being exceptions.

Nevertheless, as Ball also stated (1918 a, page 19), '. . . the medium to low grade formations are persistent', and it is felt that exploration and development of the lesser leases has been neglected. Three old diamond drill holes on the Caledonia leases struck 4 to 10 feet of ore with reported values of 10 percent and 20 percent copper at a depth of 150 feet; and it is surprising that these results have never been followed up, and, as good enriched ore and medium-grade primary ores are known to occur at some depth below the surface in the Cardross area, further test drilling seems warranted.

The *Mountain Maid* (7) and the *Spaniard* (6) are two mines respectively 6 and 4 miles south of the central L-group. At the Mountain Maid the outcrop consisted of a tourmaline-bearing cellular gossan containing malachite and azurite. The host rocks—gneiss and quartz-mica schist—are kaolinized and iron-stained at the surface. Several shafts were sunk, the deepest of which was 185 feet. The Spanish lode forms a long line striking 330° in gently undulating quartz-mica schists. Shafts and trenches have been opened up over a distance of about 400 feet.

Small workings are known in the Pandanus Creek and Welcome Creek areas, and include (?)*Buchanan's* (8) and (?)*Jessica.* Dumps reveal the presence of pyrite, arsenopyrite, and chalcopyrite.

A group of scattered small workings 1½ to 2 miles north-west of Cardross in gently undulating mica schist is known locally as the Arizona group. These workings consist of shallow shafts and pits in altered material stained with copper carbonates.

Dargalong Group (21)

(Jack, 1891; Q.G.M.J. 1906a; Ball, 1917c; Jensen, 1941)

The Dargalong silver-lead lodes, situated approximately 8 miles south-west of Chillagoe in granulite, mica schist, gneiss, and amphibolite of the Dargalong Metamorphics, were first mentioned in Warden's Reports for the year 1889. Work was done intermittently, and the main periods of activity appear to have been between 1909 and 1915, and between 1923 and 1925. The total production for these years was some 667 tons of ore which yielded 126 tons of lead and 20,680 ounces of silver, corresponding to an average recovery grade of 18.8 percent lead and 31 ounces of silver per ton. The copper content was negligible: only 2.2 tons of copper were obtained.

The lodes occur in a north-west-trending shear zone. According to Ball (1917c) the main Dargalong lode is made up of '. . . a number of nearly parallel, sometimes overlapping and sometimes intersecting formations', whereas Jensen (1941) thought that the main Dargalong lode is a continuous shear, with a zone of fracturing containing diagonal branch lodes on the western side of the main lode. The main lode can be traced for a distance of two miles (Ball) to four miles (Jensen), and dips 60° or more to the south-west. The rich ore-shoots appear to have been very short, ranging in width from 6 inches to 12 inches, and according to Jensen '. . . lie en echelon on the stratification coming into the main lode at an angle but not extending far from the main 'lode'. The lode, sensu lato, is between 6 inches and 6 feet thick, and is composed of 'ironstone' and quartz. Where the lode traverses mica schist the grade of ore is higher than where it passes through the other rock types.

High-grade oxidized silver-lead ores, including cerussite, anglesite, and massicot, have been extracted in small quantities near the surface. Below the groundwater level the ore is low-grade, complex, and siliceous, and consists of argentiferous galena, pyrite, sphalerite, and some chalcopyrite. Bismuth and stibnite were known from some of the shoots.

Workings generally were small, disconnected, and shallow. The *Jubilee* (21, a) was the most extensively worked and had a shaft 200 feet deep. In the 90-foot level of its No. 1 shaft the lode was 2 feet wide and assayed 25 percent lead, 50 ounces of silver per ton, 2 percent copper, 12 percent zinc, 12 percent iron, and 20 to 25 percent sulphur.

An extension of the lode on the western slope of Mount Delany (16) shows copper carbonates at the surface.

Bamford Area (58,c,d,e,f)

Near the Dover Castle tin mine (see page 103) there are several workings from which silver-lead ore has been won intermittently since 1890. The workings were then known as the Lappa-Lappa mines, and are situated in the Featherbed Volcanics about 4 miles north-west of Petford.

The *Comstock* lode (58, c), which is on a hill less than a quarter of a mile from the Dover Castle tin mine, is siliceous with iron-stained and gossanous portions. Several veins up to 4 feet wide have been worked in pink to grey-green quartz porphyry. They are generally steeply-dipping to vertical, and pinch and swell in width from a few inches to 2 or 3 feet. Silver values were high in the early period: Jensen (1919) reported 38.5 ounces of silver per ton and 35.8 percent lead in galena ore. In 1961 the lease holder of the Dover Castle tin mine, Mr Bagden, had re-timbered the Comstock shaft and had extracted from it a parcel of ore apparently very rich in galena; however, he told us that there was very little good galena ore left in the lode, and that the percentage of sphalerite increases markedly with depth.

Small but rich shoots of galena ore were worked in white quartz porphyry at the *Silver Bead* (58, d), a few hundred yards west of the Comstock. The lodes apparently trend north-west, but are somewhat erratic. The mine kept up an intermittent production between 1919 and 1926.

The *Better Luck* mine adjoins the Silver Bead to the north. Galena ore found on the dumps is siliceous and pyritic. Mining was from a 3-foot-wide lode, known at its southern end as the *Sarah-James,* and the main period of activity was around 1920.

Scattered Mines

Torpey's Crooked Creek silver-lead mine (46) (Dunstan, 1905a) is 3 miles east-north-east of Almaden and can be reached by an old washed-out track 5 to 6 miles long. The mine lies in sediments of the Mount Garnet Formation, which here consists of conglomerate, sandstone, quartz greywacke, and siltstone.

The lode was described by Dunstan (1905a) as an irregular deposit, and, although some lead carbonate was exposed at the surface, there was little evidence for the presence of the rich galena ore found in depth.

A main shaft was sunk to 125 feet in 1904, and was deepened to 365 feet in 1912. Levels were developed at depths of 30, 70, 125, and 300 feet. In 1904 ore was stoped from a shoot of solid sulphides, 25 to 35 feet wide, pinching to 13 feet at the 125-foot level, and assaying about 30 percent lead. In this mine also sphalerite became increasingly abundant at greater depths. Gangue minerals were pyrite and fluorite.

Ore at the 300-foot level was reported to contain 22 percent lead and 18 ounces of silver per ton in a lode 2 feet wide. At 365 feet the orebody had become unpayable because of increasing hardness and sphalerite content, and decreasing grade and dimensions.

The main production years were from 1904 to 1907 and from 1912 to 1914. An attempt was made to re-open the mine in 1924 when a demand for zinc existed, but the attempt came to nothing and the mine has remained inactive

since that year. Production figures are not complete: the total output since 1912 is estimated at 6000 tons of ore, which yielded 84,000 ounces of silver and 920 tons of lead. In addition, in 1904, some 2000 tons of ore, for which no returns are known, is on record as having been milled, but no figures are available for the years between 1904 and 1912.

Conroy's lead workings (47, e) are located 1¾ miles north-north-east of Koorboora in fine-grained sandstone of possible Carboniferous age. The lode, generally limonitic and kaolinitic, is gossanous in places, and is here and there stained by manganese oxides. Galena, cerussite, and malachite were noted on the dumps.

Manipota (Maniopoto) (31) (Jensen, 1941) is a lode situated 5 miles north-west of Almaden, and was discovered in 1905. It is a wide contact lode composed of siliceous-ferruginous garnet rock, striking north-west for more than a mile along the boundary between limestone on the south and granite on the north. A 5-foot-wide ore-shoot carrying high-grade lead carbonate was opened up at the 60-foot level of one of the shafts and assayed 32.5 percent lead and 2.3 ounces of silver per ton. Production came from several shafts, open cuts, and trenches, and totalled about 790 tons of ore for a yield of 1340 ounces of silver and 150 tons of lead. The last development work was done in 1926 when 'a considerable tonnage of high-grade lead ore' was reported; unfortunately its silver content was low.

The *Gibraltar* (30, j) is the only working in the group of gold and fluorite mines in the Fluorspar area which yielded copper. The lode, situated in porphyry of the Featherbed Volcanics several hundred yards north of the Australia Flag gold mine, was opened up in 1897 and prospected over a width of 40 feet. A few hundred tons of ore were won, assaying between 7 and 20 percent copper.

About 3 miles south-east of Petford, close to the road from Petford to Emuford, lies the *Emerald Hill* copper mine (53). The lode is siliceous and ferruginous and carries pyrite, chalcopyrite, sphalerite, galena, cuprite, malachite, azurite, and radiating clusters of actinolite. Workings include 5 shafts and an adit. No production figures are available.

The *Silver Spray* (52) lead mine lies in conglomerate, shale, and greywacke of the Mount Garnet Formation, on the bank of Back Creek, some 8 miles south-east of Petford. The siliceous lode carries galena, sphalerite, chalcopyrite, and pyrite, and was worked by means of 4 vertical shafts, an adit, and several prospecting pits and tranches. The lode is probably part of a north-south fault system.

Smaller copper and lead prospects are found north and south-east of Ootann (40, 41, 42, 44), but are not known to have had any production worth mentioning.

The following table (Table 3) sets out, in rounded figures, the production of the more important copper, lead, and silver mines. The figures are compiled from various sources and are nearly all incomplete because the records of the Chillagoe smelters usually did not differentiate between the returns of the individual mines and centres, especially during the peak period of 1900 to 1909. Where it is suspected that this has led to more than the average discrepancies between recorded and actual production, the figures have a± sign added to them. Figures for the Redcap group of mines are probably the least complete and have therefore been given two ± signs.

Tungsten, Molybdenum, Bismuth

The Chillagoe district has accounted for most of the wolframite and molybdenite production in Queenslands, and was, until 1920, the world's largest producer of molybdenite. By far the most important centres were Wolfram Camp and Bamford Hill; minor quantities of wolframite also came from the Neville and Mavis Bruce mines (47, p) in the Koorboora area; from the Mistake and other mines in the Emuford district; and from the Scardon's area (45) north of Almaden. Molybdenite was also won from the Khartoum area (38) south-west of Almaden.

Wolframite was first found in 1894, almost simultaneously at Wolfram Camp and Bamford Hill, and enjoyed its biggest boom period during the years of the first World War, when prices between £100 and £200 per ton were being obtained. In 1921 production almost stopped because the Queensland deposits could not compete with the post-war large-scale production in the United States, India, and China, which developed under the stimulus of prices higher than were paid in Australia under the tariff fixed by the Commonwealth Government. Since then production has been small and intermittent, and has been governed chiefly by the erratic fluctuations of the price of wolfram. A minor boom occurred from 1938 to about 1945; production struggled on until about 1955, and finally died out in 1958.

Although molybdenite was discovered at about the same time as wolframite, the mineral could not be sold for lack of demand until 1900. Its price then rose quickly from £52 per ton in 1900 to almost £200 per ton in 1902. In 1913 the price increased sharply to £325, and reached £500 per ton in 1914—the beginning of the war boom. In 1920 production collapsed, and has since been intermittent and negligible.

Bismuth has been a by-product, produced in far smaller quantities than wolframite or even molybdenite. The mineral is difficult to separate from wolframite because of its similar specific gravity, and was therefore often sold as a mixed wolframite-bismuth concentrate. A percentage of less than 3 percent in the mixed concentrate was considered an impurity, and was penalized, whereas percentages of more than 3 percent were paid for.

TABLE 3

Production Fgures (Incomplete) of the Principal Copper and Lead Mines.

Name of mine or group of mines	Main periods of recorded production	ORE (Tons)	COPPER (Tons)	LEAD (Tons)	SILVER (Ounces)	GOLD (Ounces)	Main references
Mungana Mines	1894-1897, 1901-1914, 1921-1927	333,600	7,910	31,835	3,228,600	?	Jensen (1920, 1941); Broadhurst (1952, 1953)
Redcap Mines	1896-1897, 1906-1911, 1925-1930	13,000±	300±	525±	23,500±	?	Morton (1927); Jensen (1941); Broadhurst (1952, 1953)
Zillmanton	1902-1930	35,000	1,500 ?	—	?	?	Jensen (1941); Branch (1960)
Ruddygore	1896-1909	32,750	1,450	—	60,000	?	Broadhurst (1949); Branch (1960)
Calcifer Mines	1894-1926	26,450	1,555	(400 bullion)	20,400	—	Jensen (1941)
Chillagoe Consols	1903-09; 21-26	30,500	1.5	6,500	450,000	—	„ „
Ti-tree	1923-1942	32,800±	400±	7±	10,800±	1,760±	„ „
Muldiva Mines	1893; 1909-26	19,010	270	1,150	315,000	—	„ (1923)
Cardross Mines	1899; 1902-22; 1931-1939	18,000±	2,000±	—	87,200±	2,200±	Ball (1918)
Christmas Gift	1910-1927	8,500	85	500	27,700	—	Jensen (1941)
Lyonite Hills	?	2,000±	0.1	190±	6,500±	—	„ „
Torpey's Crooked Creek	1912-13; 1924	6,000±	1.0	920±	84,000±	—	Dunstan (1909)
Dargalong Group	1909-1915, 1923-1925	670	2.5	130	20,700	—	Jensen (1941); Ball (1917)

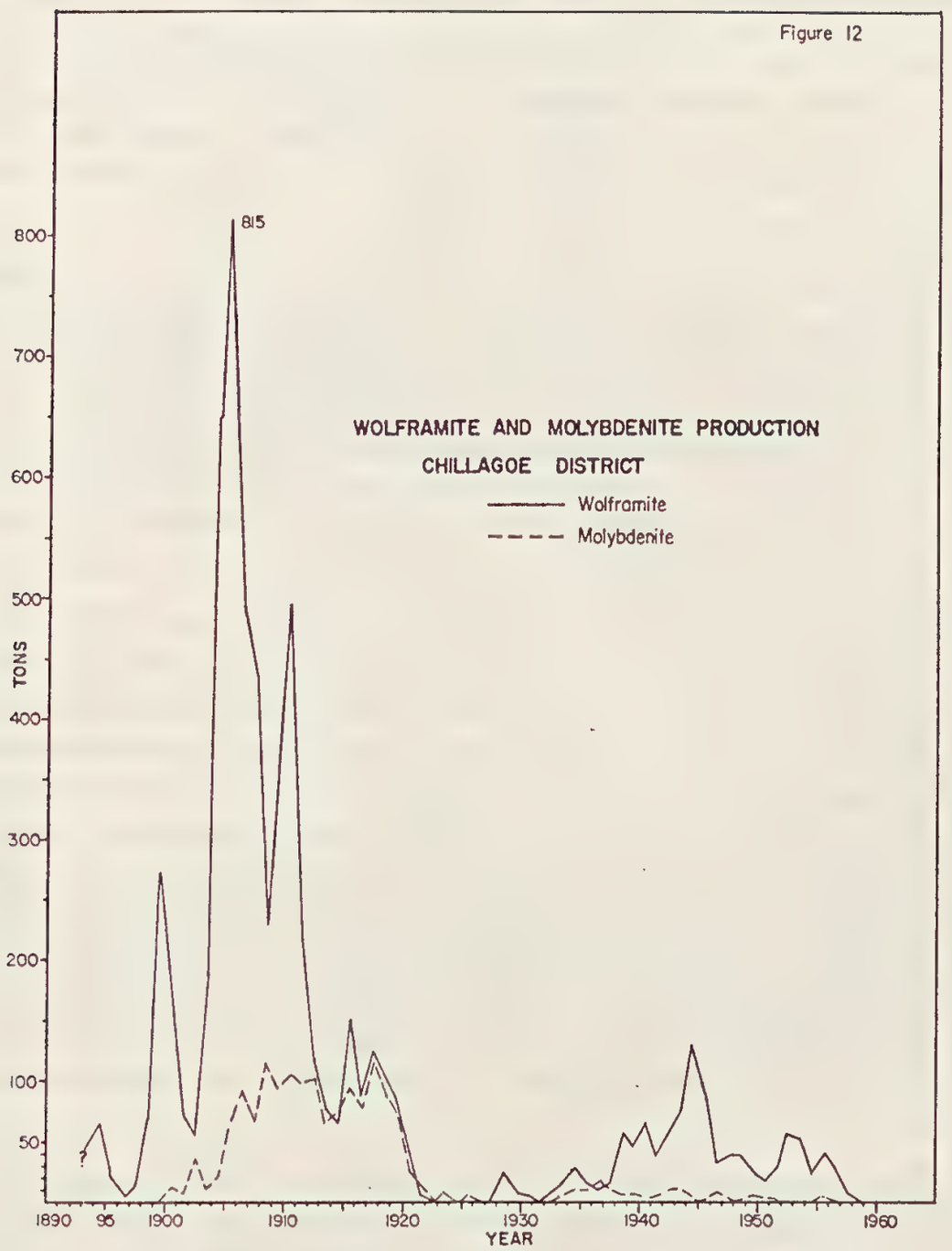


Figure 12
815
800
700
600
500
400
300
200
100
50
TONS
WOLFRAMITE AND MOLYBDENITE PRODUCTION
CHILLAGOE DISTRICT
Wolframite
Molybdenite
1890
95
1900
1910
1920
1930
1940
1950
1960
YEAR

The total value of the production from the two main centres, Wolfram Camp and Bamford Hill, has been estimated at roughly £1,150,000.

Wolfram Camp (60)

(Cameron, 1903, 1904; Dunstan, 1905b; Ball, 1913a,b, 1919a, 1920; Williams, 1923; Clappison, 1941; Morton & Ridgway, 1944b; Morton, 1945; Ridgway, 1946; Blanchard, 1947; Queensland Department of Mines, 1953; Connah, 1954)

Wolfram Camp, 15 miles north-west of Dimbulah by road, has been Queensland's most prolific wolframite and molybdenite field. Production up to 1960 amounted to about 5400 tons of wolframite concentrate, 1455 tons of mixed wolfram-bismuth concentrate, 1355 tons of molybdenite concentrate, and 80 tons of bismuth concentrate.

The first production of wolframite came from detrital deposits concentrated in creeks and in the 'loams' at the surface. The price of wolfram was then £10 per ton. It rose slowly until it became—at about £56 per ton—high enough to attract more attention. Detrital deposits continued to form the main source until, about 1906, they became exhausted, and most subsequent production was from lode deposits. In 1900 a market was found for molybdenite, which added to the attraction of the field, and Australia became the world's largest producer of this mineral (Daly, 1959).

In 1906 the Irvinebank Mining Company began to buy its way into Wolfram Camp, and by 1907 owned, or had a controlling interest in, most of the important claims. A battery was opened in 1908, and the company continued operations until 1917, when its mill and many of its mines were taken over by the Thermo Electric Ore Reduction Corp. Ltd. In the meantime a French company, the Société Française des Métaux Rares, had bought several mines and had erected a costly plant designed to treat low-grade mixed metal ore, but after some short and unsuccessful trial runs in 1912 operations had ceased and the company had gone into liquidation. The Thermo Electric Ore Reduction Corp. Ltd constructed a ten-million-gallon water dam and a 20-head battery, and equipped some of the largest mines with haulage and compression units; however, the sudden collapse of the market in 1920 forced it into liquidation.

An attempt to rejuvenate the field was made in 1926 by Queensland Rare Metals Co., who erected a battery on the site of the old Irvinebank works, but adverse market conditions soon caused the abandonment of the attempt.

The Queensland Government assisted the field by taking over control of the battery from 1942 to 1956. In 1958 the battery was operated by Kensington (Qld) Pty Ltd for the recovery of molybdenite, but, when the site was visited in 1961, it was abandoned and the battery had been completely dismantled.

In 1959, at the request of Kensington (Qld) Pty Ltd, the Bureau of Mineral Resources carried out tests with a portable scintillometer detector over a number of workings to determine whether or not the orebodies showed any well-defined radioactivity (Daly, 1959). This method was tried because it was known that many molybdenite samples were slightly radioactive, and because conventional geophysical methods were unsuitable. However, the field method failed to indicate more than the slight erratic values generally encountered over granitic rocks. Examination of one of the radioactive specimens in the Bureau of Mineral Resources laboratory in Canberra showed the radioactivity to be associated with xenotime, an yttrium phosphate in which part of the yttrium may be exchanged for cerium and thorium (Roberts, 1959).

The workings are situated in granite which has intruded the sediments of the Hodgkinson Formation and massive (?)Permian porphyries. The granite contact dips north at 50° or more; sediment remnants on top of some of the granite hills show that the granite boundary was more or less horizontal; the exposures are, therefore, in the roof area of the intrusion. The northern periphery of the granite is greisenized to various degrees, and the mineralization is confined to the greisen, in particular along and near the northern boundary in a zone 2 miles long, and up to 2500 feet from the contact (see inset, Plate 13).

The deposits at Wolfram Camp may be classified as:
a) detrital surface deposits, b) flat lodes, c) disseminated ore, d) segregations, and e) quartz pipes. Of these, the detrital deposits yielded most of the initial output, but the quartz pipes have provided the most important part of the production.

a) The detrital deposits were the first to be worked, in creeks and gullies around Wolfram Camp, and in 'loam' deposits at the surface. They must have represented a large percentage of the total ore won, but were worked out by 1906.

b) The flat lodes occurred only in the high parts of the field, near the roof of the intrusion where the former granite boundary was flat and had induced, on cooling, a system of flat contraction joints which subsequently became filled with mineralized quartz. These lodes were never of any significance.

c) Disseminated orebodies in greisen. This kind of deposit, which was an important source of rare metals in some of the mines, is known locally as 'spotted dog' or—where containing finely disseminated molybdenite—as "spotted dog lig'. Clappison (1941) was in favour of directing more attention to prospecting these disseminated but relatively large deposits, and considered that the future of the field largely depended on them.

d) Segregations and pockets of ore are scattered through the greisen zone, but are small, and can only be found by chance.

e) Quartz pipes have been the most extensively worked deposits. They are irregular and tortuous, of varying shape and size, and show inconsistent pitches

commonly changing in attitude. The pitch may range from horizontal to vertical. Most of the pipes are inclined towards the granite contact, and in some places follow the contact downwards. They commonly change direction where abutting joints, faults, and barren quartz reefs, and are commonly greatly enriched at contacts with faults. There is no sharp boundary between pipes and surrounding greisen: the quartz filling gradually passes first into greisen and then into only slightly altered granite.

Of the 250 or so pipes known, only a small number have been worked to depths greater than 50 or 100 feet, and very few have reached a depth of more than 500 feet. Branching is common and many of the off-shoots, though rarely extending more than 30 or 40 feet from the main pipe, carry rich concentrations of the rare metals. The pipes are roughly circular or elliptical in section, and have diameters ranging from a foot to more than 30 feet, though the average is about 5 to 6 feet. Maximum dimensions reported are 45 feet by 30 feet, 34 feet by 14 feet, and 28 feet by 18 feet.

The greater part of the pipe filling is white to blue glassy quartz, generally containing less than 1 percent wolframite and molybdenite. Ore occurs in shoots at various intervals, and it appears that the extent of 'blanks' between the ore-shoots increases with depth. There is no constant relationship between ore-shoots and 'blanks'. Vugs in the pipes range in diameter from a few inches to several feet, are up to 20 feet long, and are generally lined with quartz crystals.

The ore-shoots commonly contain from about a hundredweight to several tons of ore with grades between 1 and 50 percent. Williams (1923) thought that there was a general impoverishment at depths greater than 200 to 300 feet, but since his report was written pipes have been worked successfully to 400 and 500 feet. No control for the distribution of the shoots is apparent, but it is stated that bends in the pipes are usually favourable loci for ore concentration.

Amongst old leases and workings located during the 1958 survey were the Tully, Forget-me-not, Larkin Amalgamated, Leisner, Murphy & Geaney, Pinwell, Mulligan, Harp of Erin, Enterprise, Victory, Finnigan, Avoca, Killarney, and Nil Desperandum. The Four Mile workings (61) lie about 2 miles to the west-north-west of Wolfram Camp in a tongue of granite bounded on the east and west by Featherbed Volcanics, and on the north by sediments of the Hodgkinson Formation. Only seven men were engaged on the Wolfram Camp workings in 1958; in 1961 three families were active on the Forget-me-not and Harp of Erin leases.

Wolframite—here a ferberitic variety—predominates over molybdenite in most pipes, and occurs at random in the ore-shoots, whereas molybdenite is usually concentrated on the outer edges (Morton & Ridgway, 1944b), with a preference for the footwall side of the pipe. Though generally separate, in

places the two minerals are intergrown. An assay of a molybdenite specimen showed 93.5 percent MoS_2, 3.38 percent Bi_2S_3, 1.15 percent SiO_2, 0.15 percent Al_2O_2, and 0.57 percent FeO. The bismuth in this specimen was present as films 0.002 to 1.0 mm. thick, within the foliation planes of the molybdenite (CSIRO, 1940).

Bismuth is very commonly intergrown with wolframite, or is present as small rounded blebs in the mineral.

In addition to the actual ore minerals—wolframite, molybdenite, and native bismuth—minor amounts of scheelite, bismuthinite, arsenopyrite, chalcopyrite, pyrrhotite, sphalerite, galena, stibnite, pyrite, tetrahedrite, calcite, tourmaline, cassiterite, and topaz have been recorded (Ball, 1920). Arsenopyrite is common in some of the pipes, and sporadic aggregations of pyrite, and, in one place, of pyrrhotite are known.

The following comments concerning the future prospects of the field are worth noting: the old pipes are not an atractive mining proposition; they are so unpredictably irregular that it is necessary to follow them step by step and efficient haulage from greater depths consequently becomes a problem. New pipes are difficult to find: geophysical methods are apparently ineffective, and drilling (although recommended by Clappison in 1941 and by Williams in 1923) would probably offer less than reasonable chances of success—even the largest diameter pipes would make an uncommonly poor target for a drill, particularly as the drill-site would have to be haphazardly chosen. Capital expenditure on the development of the lower-grade disseminated ores is discouraged by the erratic behaviour of the tungsten market and the fact that at present there is no known evidence pointing to large reserves. However, this type of orebody is a more favourable drilling target; also, the molybdenum market is considerably more reliable than the tungsten market, and the discovery of a large body of 'spotted dog lig' containing as little as 0.3 percent molybdenum could provide a good mining prospect. This is probably the only sort of possibility for any substantial revival of the field—the reserves remaining in the old pipes offer only limited scope to individual syndicates at times when the price of tungsten is high and stationary for a reasonable period.

Bamford Hill (57)

(Cameron, 1904; Ball, 1913a, 1914b; Morton, 1940; Blanchard, 1947; Levingston, 1955)

A second important wolframite-molybdenite field, Bamford Hill, is situated 2½ miles along a track north-north-west from Petford. The geological setting and the pattern of mineralization are very similar to those at Wolfram Camp: quartz pipes occur along a stretch, 1½ miles long and a quarter of a mile wide, of greisenized granite and in close proximity to its contact with the intruded (?)Featherbed Volcanics (see inset, Plate 13). However, greisenization is not

as intensive as at Wolfram Camp. Here, also, the first ore was won from rich detrital deposits at the surface which were exhausted by 1906, whereafter the quartz pipes became the chief producers.

The first discovery of wolframite in this field was made in about 1893, and the first real boom took place during World War I. A State Battery was opened in 1917 and allowed the working of lower-grade ore. After the crash in 1920 production stayed insignificant until a small revival after 1938. The State Battery closed down in 1949, and by 1958 the field was completely deserted. The total production, in round figures, up to the end of 1945 is given by Blanchard (1947) as: 1880 tons of wolframite, 100 tons of wolfram-bismuth concentrates, 165 tons of molybdenite concentrate, and 20 tons of bismuth concentrate.

Among the leases and workings located during the 1958 survey were the *K.Y., Haymaker, Brandon, Gillian and Bridge, Osbourne, Nelsen's, Rose of Queensland, Rollison, Plum Pudding, Ballarat, Tiger's Tail, Sunny Corner,* and *Shady Corner* (57). The deepest working was probably one of the Brandon shafts, which was about 608 feet along the incline. Production figures are not complete. The *Eight Mile* mine (59), in a small granite outcrop 3 miles north of Bamford Hill on the east bank of Emu Creek, was also worked for wolframite and molybdenite.

The minerals encountered in the 70 quartz pipes worked have been described by Ball (1915) and include, apart from the ore minerals wolframite, molybdenite, and bismuth, also small quantities of scattered sphalerite, pyrite, chalcopyrite, galena, fluorite, kaolin, magnetite, and various tungsten, molybdenum, and bismuth minerals such as scheelite, powellite, and bismuthinite. Many of the sulphides are commonly found concentrated in the vugs, and the proportion of sulphides seems to increase with depth.

The wolframite, which is nearer ferberite than hubnerite in composition, has a high content of tungstic acid. An analysis by the Government Analyst in 1905 gave the following results: 73.0 percent WO_3, 7.81 percent MnO, 14.15 percent FeO.

There is less information on the Bamford Hill workings than on those at Wolfram Camp, but the conditions are essentially the same, and a large-scale resumption of mining operations, in the event of a return of favourable tungsten prices, cannot be envisaged.

Khartoum district (38)

(Saint-Smith, 1917a, 1917c)

Khartoum was a small mining settlement about 9 miles south-west of Almaden, and 2½ miles west-south-west of Ootann. Molybdenite had been mined from several workings since 1914, and Saint-Smith had great expectations of the district because of 'the large tonnage of highly-payable ore already fully proved and developed', the absence of impurities, and various other factors.

However, by 1918 all the proved ore had been extracted and no further ore was discovered, and since 1919 the district has not been mentioned in Warden's Reports. Production figures are not known.

The country rock is grey to pale pink, medium-grained, hornblende-bearing biotite granite (?Herbert River Granite) which is intruded by numerous and extensive dykes and stocks of a fine-grained acid granite containing biotite (?Elizabeth Creek Granite). Parts of the granite are greisenized, and small pegmatite veins have been reported. Numerous quartz reefs occur '. . . along the margins of, and also constitute extensions of, the later acid intrusions' (Saint-Smith, 1917a). They have no preferred direction of strike, are commonly sinuous and low-dipping, and the amount of dip varies in each individual lode. According to Saint-Smith they consist of a series of slightly overlapping lenses, and are accompanied by numerous stringers and veinlets of quartz branching off the main lode. Molybdenite values were usually highest in the widest parts of the lodes. In the Kitchener mine the highest values were found in the steeper-dipping portions. The only ore mineral of any importance is molybdenite.

In the upper 35 feet of the lodes the mineral is generally decomposed and leached out, or has been altered to powellite or molybdite. At the Kitchener mine the concentrate was said to have assayed 93 percent MoS_2, and hand-picked ore from the dump contained 96.5 percent MoS_2.

Some wolframite has been recorded from Jackson's Lode and Mount Riddell and two other leases. Bismuth is known only from the Jackson's Lode. Sulphides are extremely rare in all the lodes: the Corporal Lease was the only locality where some galena, chalcopyrite, and up to 8 percent cassiterite were found, and a little pyrite occurs in two or three of the leases.

The most important mine in the area was the *Kitchener* (38, d), and second to it was the *Ajax* (38, c). The Kitchener, located on Tate Spring Creek, was originally opened up by a prospector named Riddell, and later taken over by Alexander Macdonald, who erected a ten-head stamp battery and flotation plant in 1917. The main shaft was 130 feet deep at the time of the Saint-Smith inspection. The lode, at the 70-foot level, dips 25° to the north, but the dip changes several times and ultimately reaches 45° at the deepest part worked, between the 120-foot level and the bottom of the shaft. The average thickness of the lode between the two levels was 4½ feet, and Saint-Smith estimated the average tenor of the ore at 3.4 percent molybdenite.

The Ajax lode was situated several hundred yards west of the Kitchener on Middle Creek. Its main shaft reached a depth of 92 feet.

Koorboora area

(Ball, 1911)

Several of the tin mines in the Koorboora area, for example the Two Jacks, contained varying amounts of wolframite in the upper parts of their lodes, but

in only three mines was the wolframite sufficiently concentrated to be mined. The mines are situated in steeply-dipping micaceous sandstone and shaly siltstone of the Mount Garnet Formation, which are heavily iron-stained near the surface.

The *Neville* (47, p), a little more than one mile south-south-east of Koorboora, was an important wolfram mine between 1904 and 1909, and was then considered as one of the greatest single wolfram mines in the world. It was worked by the Irvinebank Mining Co. and had yielded 550 tons of wolframite by 1909. War-time demand resulted in some further production in 1918, increasing the recorded total output to 580 tons of wolframite from 8583 tons of ore.

Nearly all ore came from one small but very rich shoot shaped as a more or less spiralling pipe, 10 to 20 feet in diameter, extending down to 140 feet. At greater depth only low-grade ore was found. The average grade in the upper 80 feet was 10 percent wolframite; between 80 feet and 120 feet the ore contained about 20 percent wolframite; below this was 20 feet of 4 percent ore. In the lower workings cassiterite made its appearance, and sulphides became increasingly abundant from the 200-foot level downwards.

The Neville was worked intermittently by prospectors for a long time after its demise as a company mine.

The *Telegraph* wolfram and tin workings adjoin the Neville mine; the orebody carried cassiterite, galena, chalcopyrite, and bismuth with the wolframite, commonly intimately intermixed. Workings were reportedly unpayable below 90 feet, and the mine has long been abandoned.

One mile north-west of the old Neville mine is the *Mavis Bruce* wolfram lode, discovered in 1943 (Morton, 1944b, 1946). The ore occurs in bunches, up to about 1 foot across, of almost pure wolframite in a spurred lode pipe, along a major joint striking north-north-west and dipping 20° to 55° to the west. The lode is altered near the surface to a kaolinite-quartz-chlorite-limonite mixture. The abundance of gossanous limonite points to a considerable original proportion of sulphides.

Although conditions looked promising, further development failed to discover any large quantities of economic ore, and after 1947 the mine was no longer mentioned in Warden's Reports. The total production consisted of some 75 tons of wolframite concentrate.

During a visit in 1961 we noted that the workings in the Koorboora area locally carry small quantities of fluorite and molybdenite.

Scardon's area

(Ball, 1911)

Situated 5 to 6 miles along a bush track north of Almaden, the Scardon's area may be divided into a western group of mines around Shannon's Hill—

Scardon's Bottom Camp—and an eastern group on Convict Creek—Scardon's Top Camp. The greatest amount of activity has been around *Scardon's Top Camp* (45, b), where the workings lie close to the contact of granodiorite and leucogranite with folded sandstone of the Mount Garnet Formation. Wolframite and molybdenite occur in white to clear glassy quartz veins which appear to be controlled by joint systems. Boundaries between the quartz lodes and the granite are gradational. The first production came from shoad deposits, but when these were exhausted shafts were sunk into the primary ore, which persisted to 70 feet (the bottom of the deepest shaft). Workings are concentrated along a zone trending 280°.

Scardon's Bottom Camp (45, a) workings were largely for shoad deposits, but two shallow shafts were eventually sunk on a narrow quartz lode in the granite.

The total production up to 1911 was reported to be roughly 30 tons of wolframite concentrate (Ball, 1911).

Emuford area (51)

Several of the mines in the Emuford district fall within the boundaries of the area under discussion, and can be easily reached by road from Petford. Many of them were worked for wolfram, others for tin, fluorspar, and copper, but no production figures are available. These lodes were generally small and insignificant.

The *Mistake* mine (51, e), about 7¼ miles south-south-east of Petford, was opened in 1915, primarily for wolfram. Since then, in addition to fluorspar, wolframite has been produced intermittently. For a description of the mine see page 113.

The *Mystery* mine (51, k), 1 mile south of the Mistake workings, occurs in pink granite close to its contact with conglomerate and quartz greywacke of the Mount Garnet Formation. Much of the host rock around the now abandoned mine is greisenous. Wolframite was worked in patches down to 180 feet in the main shaft, and bismuth, galena, chalcopyrite, and copper carbonates were noted in small quantities. A parcel of 9 percent copper ore was extracted from the mine in its early stage. The quartz gangue contained some fluorite and topaz.

Some wolframite has been won from the shallow *Gold Rod* workings (51, f) in granite and greisen south of the Mistake mine.

The *Spotted Dog* (51, b) lies about 1 mile north-west of the Mystery. Wolframite occurs here in sediments of the Mount Garnet Formation.

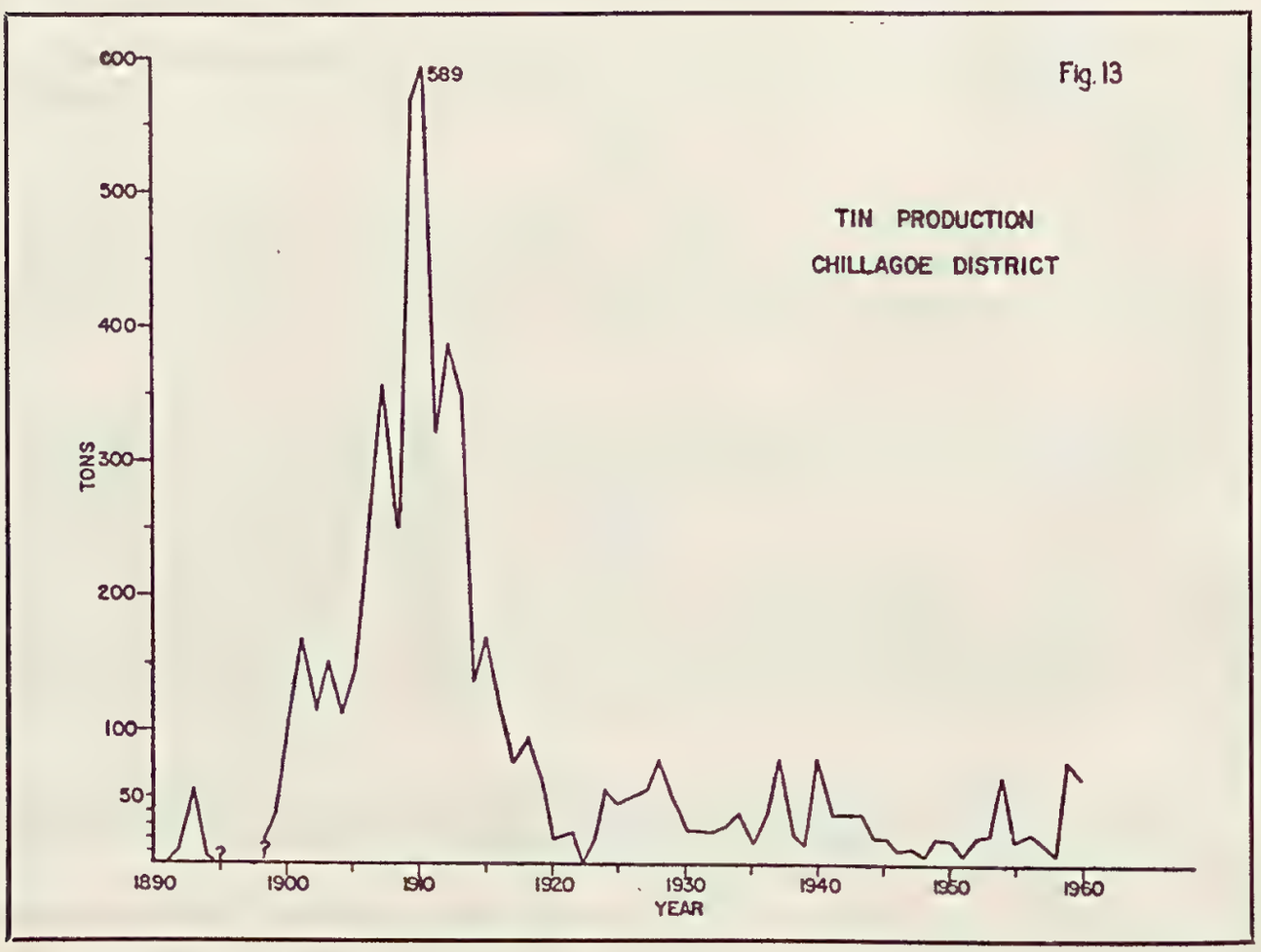
The *Sydney* (51, i) is one of a group of tungsten prospects south of the Mystery mine. A shaft, 31 feet deep, with levels at 15 feet and 26 feet, has been sunk in a mineralized quartz vein in granite striking 325°.

Some wolframite has been won from the *Tommy Burns* tin mine (48, f) just west of the Sunnymount Battery (see page 101).

The *Indicator* wolfram workings are located 5 miles west of the old Spinifex railway siding on the now abandoned Mount Garnet line. Host rocks are sandstone and siltstone that are commonly chloritic. The mine is not far from pink granite and massive grey porphyry of the Boxwood Ring Complex. Shafts were sunk to depths of more than 100 feet on a thin vein, and produced some 15 tons of ore during the years 1917 to 1919.

Tin

Tin mining has mainly been centred in the Koorboora and Sunnymount districts and north-west of Bamford Hill. The recorded production of some 5890 tons of cassiterite is small compared with that of the much more important Herberton Tin District, which borders the area to the south-east and which has been mined for tin since 1879. The first tin in the Chillagoe district was found near Koorboora more or less accidentally during the search for a suitable dray



road from the newly discovered Chillagoe copper workings in the west to the shipping centre of Cairns in the east. Mining of alluvial cassiterite was soon in progress. Between 1900 and 1917 many of the lodes in the Koorboora area

and—from 1908—in the Sunnymount area were extensively worked. A battery was erected at Sunnymount in 1910. Production declined after 1912, principally owing to labour trouble, but it seems that the old lodes must have been approaching exhaustion, for, from 1917 to 1920, despite the very high tin prices prevailing, production was practically confined to the comparatively newly discovered Two Jacks mine. After the Two Jacks closed in 1920 tin mining was intermittent and on a generally low level of activity. In 1952 Bird and Markwell erected a ten-head stamp battery at Sunnymount, which has since been treating most of the tin ores from the district. The latest pick-up in production came in 1959 with the development of a new, rich ore-shoot in the old Dover Castle tin mine, which has been virtually the only tin producer in the Chillagoe district since 1958. Owing to the high tin prices of the last few years, interest in the metal has been high, and the area has recently attracted some attention from some of the larger mining companies. An Authority to Prospect in the Sunnymount-Koorboora area was granted to Broken Hill Pty Co. Ltd in 1960.

The mineralization in the Koorboora and Sunnymount areas is closely similar to that in the Herberton district: the lodes are ill-defined bodies of mainly chloritized, kaolinized, and to some extent pneumatolytically altered sandstone, siltstone, and quartz greywacke, and merge gradually with the unaltered host rock. They contain ore-shoots that tend to be irregularly pipe-like and are apparently controlled by fissure and joint intersections that have served as migration channels. The ore-shoots change gradually to barren rock.

The granite responsible for the hydrothermal-pneumatolytic alteration (chloritization, formation of muscovite, garnet, tourmaline, cassiterite, wolframite) is undoubtedly present at no great depth in the Koorboora area: at the Mountain Maid (54), for instance, blocks of granite have been found on the dumps, and in the Sunnymount area the granite batholith is widely exposed just east of the mines.

Most of the lodes in the Koorboora and Sunnymount areas carried some wolframite in their upper parts, and a couple of mines have been worked exclusively for wolframite (see page 95). In the bottom parts of the lodes an increase in the proportion of base-metal sulphides is commonly noticeable, and as treatment of the complex ore is costly the mining of deeper ore-shoots of this type has little attraction.

Koorboora area (47)

(Cameron, 1904)

The *Shakespeare* tin mine (47, k), situated near the Almaden-Petford road on the site of the old Koorboora settlement, is one of the earliest and most extensively worked mines in the area, but carried comparatively low-grade ore, judging from the reported production figures: 203 tons of cassiterite from 14,539 tons of ore between 1901 and 1947.

Two lodes were opened up: a western lode carrying galena, chalcopyrite, pyrite, and arsenopyrite in addition to cassiterite; and a more important eastern lode of ferruginous and chloritic material striking north-west and dipping north-east, which has accounted for the main portion of the output. Open cuts and shafts yielded payable tin to a depth of 200 feet. The host rocks generally contain much mica and sericite as a result of pneumatolytic action.

The *Argo* workings (47, h), now collapsed, are on a small lode 1 mile south-west of the Shakespeare. Adits, 262 and 115 feet long, were connected with shafts 60 feet and 65 feet deep.

Just north of the Argo are the *Southwick* workings (47, g), opened in 1905, and including a shaft with a depth of 240 feet and a drive 137 feet long. Production came from a small rich seam striking north-west, and included 15 tons of cassiterite from 240 tons of ore in 1905. and 13½ tons of cassiterite from 38 tons of ore in 1915.

The *Tennyson* mine (47, m) (Blanchard, 1947) is about three-quarters of a mile south of the Koorboora railway siding, and was worked from 1905-1916 mainly by the Irvinebank Mining Coy. It was re-opened in 1926 by Queensland Tin and Metal Mines N.L., only to close one year later. The host rocks are commonly pneumatolytically altered, and consist of chloritized and greisenized sandstone and siltstone striking about 20°. A dyke in the workings is assumed to have influenced the deposition of the ore. This dyke, referred to in the literature as the Tennyson dyke (not to be confused with the Tennyson Ring Dyke), consists of numerous fragments, ranging up to several feet in length, of chert, quartzite, rhyolite, and porphyry, in a light-grey tuffaceous matrix. The ore occurs in shoots in chloritic material occupying fissures that evidently opened after the dyke formed, as the fissures cut the dyke; and also as small veins and irregular pipes against, or close to, the dyke.

Workings are grouped around the Central Shaft (186 feet deep), and Eade's Shaft, 260 feet away. The Central Shaft has plats at 88 feet, 145 feet, and 174 feet. Eade's is an inclined shaft on the footwall side of the orebody; it is 185 feet long and has levels driven south at 80 feet, 114 feet, and 175 feet.

Ore-shoots occur as pipe-like bodies within chloritized host rock which forms a 4 to 8-foot wide lode dipping steeply west; the ore-shoots are tortuous and irregular, and occur on both sides of the Tennyson dyke. Cassiterite values were reported to be from 2 to 3 percent. At depth much of the tin ore is intimately intergrown with galena, sphalerite, pyrite, and chalcopyrite, and it was necessary to market a mixed concentrate. This was one of the reasons why Morton (1927) regarded further mining below the 175-foot level as uneconomic.

Available but incomplete production records mention a yield of about 701 tons of mixed concentrates from 10,897 tons of ore (Blanchard, 1947). The main productive period was from 1904 to 1916.

The *Fair Play* (47, o) lies half a mile east of the Tennyson, along the track to the Neville wolfram mine, and was worked intermittently to a depth of 200 feet. In 1908 a shoot 40 feet long and 2 feet wide, carrying 15 per-cent cassiterite, was located. Production from 1901 to 1947 amounted to 462 tons of cassiterite from 6339 tons of ore.

The *Two Jacks* (47, r) lease, including the Three Jacks and New Dalnotter lodes, is located about 2 miles east-north-east of the former Koorboora settlement, and was one of the latest-worked deposits in the area. The workings are situated in chloritized and sericitic Mount Garnet sediments exposed as an inlier in rhyolites of the Featherbed Volcanics. The sediments are fine-grained micaceous siltstones, generally strongly brecciated and traversed by northerly to north-westerly faults which, in places, appear to displace the lodes. The ore-shoots pitch north-west and dip north-east, and form discontinuous lenses between which the crushed country rock carries low values.

The cassiterite is very fine-grained and is, in places, associated with tourmaline. Fine-grained pyrite is visible as films on joint planes. Between 1906 and 1921, 457 tons of cassiterite were produced from 11,321 tons of ore. An attempt to re-open the mine in 1926 failed. In 1960 and 1961, when they were granted an Authority to Prospect in the Koorboora-Sunnymount area, the Broken Hill Pty Co. Ltd dewatered the mine down to the 185-foot level, where ore had been extracted over a length of 30 feet and an average width of 4½ feet. Between the 120-foot and 140-foot levels large quantities of ore had been mined from a lode measuring 80 feet by 8 feet. The Broken Hill Pty Co. Ltd found the values and remaining tonnages inadequate, and subsequently relinquished their Authority to Prospect.

The *Mountain Maid* (54) is situated in fine-grained quartzitic sandstone and quartz siltstone at the northern rim of the Tennyson Ring Dyke, 2 miles east of the Two Jacks mine. Fine-grained hornblende-biotite granite occurs on the dumps, indicating the presence of granite at shallow depth.

There are records of many other mines in the Koorboora area, including the *Iolanthe, Reform, Pioneer, Portia, King Arthur, Iago, Now or Never, Atlantasaurus, Sunday* (Levingston, 1958), *Money Moon, Proserpine,* and others, but none of these mines were located during the 1958 survey.

Sunnymount area (48)

The mines in the Sunnymount area, separated from the Koorboora area by the Tennyson Ring Dyke, were discovered some twenty years after the finds at Koorboora.

The *Tommy Burns* (48, f) (Ball, 1917b), discovered in 1908, was the first and most important of these workings. The mine is situated about 2 miles west of the old Sunnymount rail siding, and can be easily reached from Petford by track. The host rocks, again, are quartzose, commonly ferruginous, micaceous,

and feldspathic sandstone and slate, mineralized along and at the intersections of fault planes and indistinct joints. The lode consists of green chloritic and red kaolinitic material containing disseminated pink garnet, and contains ore-shoots that are richest near the surface, but which show much decreased values in the deeper workings. This is also evident from the production figures for the main period of activity between 1909 and 1913: these show how the average recovery grade declined from 13 percent in 1909 to about 2½ percent in 1913. The best shoots were confined to a narrow band pitching 45° westwards from the open cut. The total amount of concentrates won between 1909 and 1913 was 370 tons from 5934 tons of ore.

Main workings include an open cut 35 feet deep, which, for the first 14 feet, yielded ore with a tenor of 10 to 25 percent cassiterite. From the floor of the open cut a shaft was sunk to a depth of 62 feet. At 106 feet below the level of the hill top an adit was then driven 253 feet; it located several large shoots of good ore. A second adit was tunnelled for 377 feet at 100 feet below the No. 1 adit, and in 1915 a third adit was driven 650 feet north-west at 280 feet below the hill crest. In 1958 the then owner, H. Bird, planned to drive south-west from the north-western end of this adit in the hope of locating the ore-bodies met in the upper levels, and had progressed 165 feet at the time of inspection. The only ore to be seen at this time was at 84 feet from the start of Bird's adit; here cassiterite, wolframite, and traces of copper were noted.

Two miles south-east of the Tommy Burns is the *Christmas Gift** lease (48, 8) (Levingston, 1958), also held by H. Bird. The lode differs from most of the other lodes in the area in that it is a cassiterite-bearing quartz vein; it has a thickness of about 15 inches, striking north-west and dipping nearly vertically south-west. The vein is about 140 feet long and is cut by a porphyry dyke in its north-western end, and terminated by a fault at its south-eastern end. Workings include two shafts and an adit driven for 320 feet south-south-west at about 100 feet below the vein outcrop, connecting with the main shaft at 140 feet. Some galena is present in addition to cassiterite. Though small, the ore-shoot was very rich: in the ten years after its discovery in 1936, 104 tons of concentrate valued at £18,973 were obtained from only 664 tons of ore. Levingston (1958) recommended driving through the porphyry dyke, as experience in the Herberton district has shown that veins commonly continue on the other side of a transecting dyke.

The *Cyclone* (48, d) is an abandoned tin mine situated about half a mile west-north-west of the Tommy Burns; in 1958 open cuts and five collapsed shafts were located in impure fine-grained quartzite striking 310°. Records show that in 1916 some 4 tons of concentrate were obtained from 74 tons of ore.

About half a mile south-west of the Tommy Burns is the *Prince Alfred* mine (48, c) (Ball, 1919b), formerly known as the Seaman mine. Cassiterite is

* One of three prospects with this name discussed in this Bulletin.

associated with tourmaline rock, vein quartz, and chloritic material. Old workings include collapsed shafts; one is reported to have been 166 feet deep. After extensive development work had located some ore with a grade of 7 or 8 percent cassiterite, 36 tons of concentrate were obtained from 481 tons of ore treated at the Gurrumbah mill (outside the area) in 1911. The lode was 20 inches wide at the south-eastern end of the 90-foot level, and contained 15 percent cassiterite, but drives at the 120-foot and 150-foot levels proved disappointing, and the lode was unpayable at the bottom of the shaft. Dumps were reworked in 1949, but the mine has been abandoned since. From 1909 to 1915, 1902 tons of ore were crushed for a yield of 182 tons of concentrate.

Other workings located in the Sunnymount area include the *Cabbage Patch* (48, e), *O'Shea's Prospect* (48, b), *New Years Gift* (48, h), and *Kerosene Tin* (48, a).

Emuford area (51)

The *Chance* mine (51, a) lies about 6½ miles south-east of Petford and 1 mile from the Petford-Emuford road, and was worked for several years by H. Bird. Cassiterite occurs in shoots in greywacke and quartz greywacke striking north-west, and a fault striking 190° is visible nearby.

Another tin mine in the area is the *Brown Snake* (51), situated 10 miles on the road south-east from Petford, and actually just outside the boundary of the area investigated. Cassiterite occurs in a quartz-veined chloritic lode in vertically tilted greywacke, shale, and some conglomerate striking 340°. Granite with greisenous margins crops out immediately west of the mine. Workings include two shafts, one of which is about 70 feet deep. In addition to tin, a small amount of copper has been won.

Bamford area (58)

About 2 miles west-north-west of Bamford Hill lies a group of tin and silver-lead workings originally known as the Lappa Lappa mines (not to be confused with Lappa Junction). The lodes are well-defined, with definite hangingwall and footwall, and are located in porphyries of the Featherbed Volcanics.

Amongst these mines the *Dover Castle* (58, b) (Denmead, 1935; Levingston, 1960) takes first place in significance; in 1959 and 1961 it was the only producing tin mine within the boundaries of the area mapped. The lode was discovered in 1890, and from 1906 was worked by the Irvinebank Mining Co. Production after 1919 was very low and came mainly from reworked dump material. In 1958 the mine was sold to C. Bagden. At this time the shaft was 300 feet deep, and local opinion considered that the lode was exhausted, for experience had suggested that all tin mines in the district lost their value at depths exceeding 200 feet. Nevertheless, after sinking the old shaft a further few

feet Bagden struck a rich new ore-shoot, and in 1961 the shaft had reached a depth of 560 feet on the incline, with no evidence of declining values.

The lode trends north-east for more than 250 feet, dips from 55° to 80° south-east, and swells and pinches from a few inches to several feet. A calcite leader is used as an indicator to follow the richest part of the lode, a high-grade layer less than one inch thick. At the shaft bottom the lode—in 1961—was about 6 feet wide and was reported to have an average grade of some 8 to 10 percent. Cassiterite occurs very finely disseminated in irregular patches and networks in a matrix of quartz, sericite, and chlorite, representing the hydrothermally altered porphyry that forms the host rock. The average grain size of the cassiterite ranges from 0.05 to 0.1 mm; observed maximum grain size is about 0.3 mm.

The ore is treated at the Sunnymount Battery, where, according to Bird, a concentrate assaying about 74 percent is obtained. The recovery grade is said to be about 6 to 7 percent. From 1906 to 1958 the total production amounted to 203.5 tons of concentrate from 2335 tons of ore. In 1959, after the new ore-shoot had been opened, production suddenly jumped to a record annual figure of 99.5 tons of concentrate from 1030 tons of ore. In 1960 a further 58.8 tons was won from 691 tons of ore, bringing the total quantity since 1906 to 361.5 tons of cassiterite. An average recovery grade of nearly 9 percent can be calculated.

A stone's throw north-east of Dover Castle is the (*King*) *Midas* lease (58, a), held by T. Rice in 1958 but subsequently taken over by Bagden. Tin mineralization occurs in altered porphyry, and the richer concentrations are in heavily iron-stained gossanous layers up to half an inch thick. The lode strikes 355°, and dips 70° to 85° east, but size and values are inferior to those at the Dover Castle. Workings include two main shafts and 40 feet of trenching along a north-eastern line. The mine has been worked to a depth of 180 feet, but is now water-logged. In 1960 some 70 tons of ore yielded about 7 tons of concentrate, but owing to the presence of galena the last operating shaft (No. 2) was abandoned; and work on the mine stopped.

Should the Dover Castle and the Midas lodes continue along their observed strikes, Bagden hopes, in due course, to find rich values at their intersection.

Some other workings are the *Christmas Gift* (58, g—not to be confused with 48, g, which has the same name), west of the Dover Castle, and the *Federal* tin mine (57, v), about 1½ miles north-west of Petford near the porphyry-granite contact. Cassiterite in the Federal is associated with tourmaline.

An isolated tin mine, without an access road, is the *Eight Mile* mine (62), situated 6½ miles north-west of Wolfram Camp in white sugary microgranite which is a local variety of the hornblende-bearing biotite granite cropping out in the area. Two shafts were located in 1958, but no particulars are known.

Gold

From the beginning of the century gold was recovered as a by-product of the copper-lead ores at the Chillagoe smelters. After 1930, in addition, several mines were worked primarily for their gold content; discoveries of rich, though small, gold lodes in the Fluorspar area in 1930 led to a minor and short-lived rush. The total production of the Chillagoe district is low. The main gold centres were the Fluorspar area and Mount Wandoo.

Fluorspar area (30)

(Reid, 1933a,b; Denmead, 1934a,b; Jensen, 1941)

Access to the Fluorspar area, which is situated along Crooked Creek about 10 miles south-east of Chillagoe, is by means of an overgrown and abandoned bush track branching off the Chillagoe-Almaden road.

With the exception of the Federal Flag mine, the gold lodes are located in biotite-hornblende adamellite and granodiorite not far from their contact with the Featherbed Volcanics. Outcrops of 'Metal Hills' granite (p. 48) in the close vicinity are composed of more basic granodiorite and quartz diorite. The granites are traversed by numerous greisenized aplite veins which probably occupy major joints and are generally low-dipping. Consequently, wherever the land-surface was suitable, several of the mines were worked by adit. Post-greisen faulting opened up small cracks and joints several inches wide that became filled with quartz, calcite, fluorspar, zeolites, and clay minerals. Where such leaders cut through the greisen veins, kaolin is generally formed, and presumably acted as a precipitant for the gold that was originally sparingly distributed throughout the greisen veins, and which would have been brought into contact with the kaolin by the last of the hydrothermal solutions carrying fluoride minerals (Jensen, 1941).

The gold is concentrated in small but commonly extremely rich shoots in the kaolin; values of several ounces of gold to the ton are normal, and figures of 20 ounces or more to the ton are also on record. Ore from very rich pockets was dollied, and the maximum reported value was 777 ounces from 9 tons of ore from the Federal Flag mine in 1932. Such richness spurred the prospectors and claim holders to feverish activity throughout the area in the thirties, and hundreds of shafts were sunk and numerous adits were driven. The mines were worked from 1930 to about 1938; records of production are very incomplete, but from what is known at least 5050 ounces of mixed bullion and fine gold were extracted by dollying and smelting from about half a dozen mines. Several hundreds of ounces of silver were won as a by-product.

The more important mines were the Federal Flag, Hiker, Blue Ensign, Golden King, White Ensign, Australian Flag, and New Zealand Flag. Some

lesser workings were the Leg Theory, Ironbark, Golden Queen, Golden Crown, and Golden Hill.

One of the first discoveries was the *Golden King* (Retchford's); 13 tons of weathered greisen and soil yielded 123 ounces of gold, but further work disclosed only small scattered patches of payable material.

The *Federal Flag* (30, m) (Reid, 1933) was the richest mine. It is situated near Convict Creek, in rhyolite porphyries and volcanic breccias of the Featherbed Volcanics. A very coarse quartz-feldspar porphyry (probably a dyke) crops out in several places around the mine. Production came mainly from a calcite-fluorite-kaolin vein which was enriched in gold at its intersection with a pyrite (?marcasite) leader, and which had a maximum width of 12 inches. The main shaft, 144 feet deep, is steeply inclined, and has apparently reached an intrusion of acid granite in depth, as is indicated by dump material.

At the *New Zealand Flag* (30, f) a quartz-halloysite vein 3 inches thick contains gold-enriched kaolin at and near its intersection with a flat-dipping joint which carries much iron oxide. Denmead (1934) thought that a ferrous iron solution percolating along the joint acted as a precipitant for the gold.

Mount Wandoo (10)

(Ball, 1918b; Reid, 1932b,d,e; Rutledge & Morton, 1933; Morton, 1935a)

The Mount Wandoo workings are situated 10½ miles west-south-west of Mungana along an abandoned bush track. Gold-mining leases were held as early as 1901, and alluvial gold was worked for some time, but by 1908 the field was deserted. There is little information from this earlier period.

In 1915 leases were taken up again by Alex Macdonald, and by 1932 much development work had been done. The 'Gold and Rare Metals Limited' company worked the lease until 1934, after which the workings were let under tribute. Mining stopped in 1937. During this period a ten-head stamp battery had been erected, and a dam for water supply, tramline, and roads had been constructed. In 1948 Broken Hill South Ltd took up some leases, but relinquished them the same year after trenching had shown very low values, of 1 dwt per ton or less.

The total production for the years 1933 to 1937 amounted to about 2100 ounces of fine gold and 7500 ounces of silver. The ore was sold to the State smelters, either as crude ore or as concentrate.

Mining was centred on two hills on the eastern bank of Muldiva Creek; the more northerly of these, Mount Wandoo, rises 250 feet above the level of Wandoo Creek. Country rocks consist of granulite and gneiss of the Dargalong Metamorphics, together with some mica schist to the north of the hills, and are intruded by some irregular pegmatite veins. The regional strike of foliation is about 330°, and the dip is about 50° north-east at Mount Wandoo. The

main workings were concentrated within a zone of altered ferruginous and micaceous gneiss, about 300 yards long. Mineralization seems to have impregnated the whole belt, but is concentrated in more ferruginous and kaolinized veins and fissures which appear to be largely controlled by faulting and jointing. Rutledge & Morton (1933) noted two types of deposit—the more important fissure deposits, and the pipes that are probably formed along the intersection of two joints or fissures. The fissures are generally steeply dipping and much branched, and are sometimes referred to as stockworks. Almost all gold is contained in the sulphide minerals arsenopyrite, pyrite, and chalcopyrite.

There were about half a dozen workings, of which the Hardman shaft was by far the most important. This shaft started at the surface in gold values of about 8 dwt per ton, which at shallow depth increased to 12 dwt per ton. At a depth of 45 feet water-level was reached, and sulphide ore started to come in—this was arsenopyrite in kaolin containing 25 dwt per ton. A large average sample from 100 feet below the surface contained about 2½ ounces of gold per ton.

The maximum shaft depth reached was 190 feet, with a winze going down to 209 feet. Levels were driven at 101, 117, and 125 feet. Ore was stoped above the 125-foot level over a width of 8 feet, which assayed 11.17 dwt (fine gold) per ton from the bulk samples. The richest find here was a 2 or 3 inch thick vein assaying 10 ounces 17 dwt of gold and 15½ ounces of silver per ton over a length of 19 feet. The winze from shaft bottom to 209 feet followed an orebody 1 foot to 5 feet wide, with a length of at least 50 feet, and assaying about 14 dwt per ton.

Pipe-like orebodies were met in the Reid and Wendy shafts; the one in the Wendy shaft was 4 feet by 4 feet in section and yielded 22 dwt of gold per ton.

Two leases—the *Beaverbrook* and the *United Empire*—situated 8 miles west-south-west of Mount Wandoo were described by Reid (1932c). There were generally only traces of gold and lead, and some ounces of silver per ton, and the leases were never developed, but the general nature of the lodes might, in Reid's opinion, indicate the presence of an enriched lode at depth.

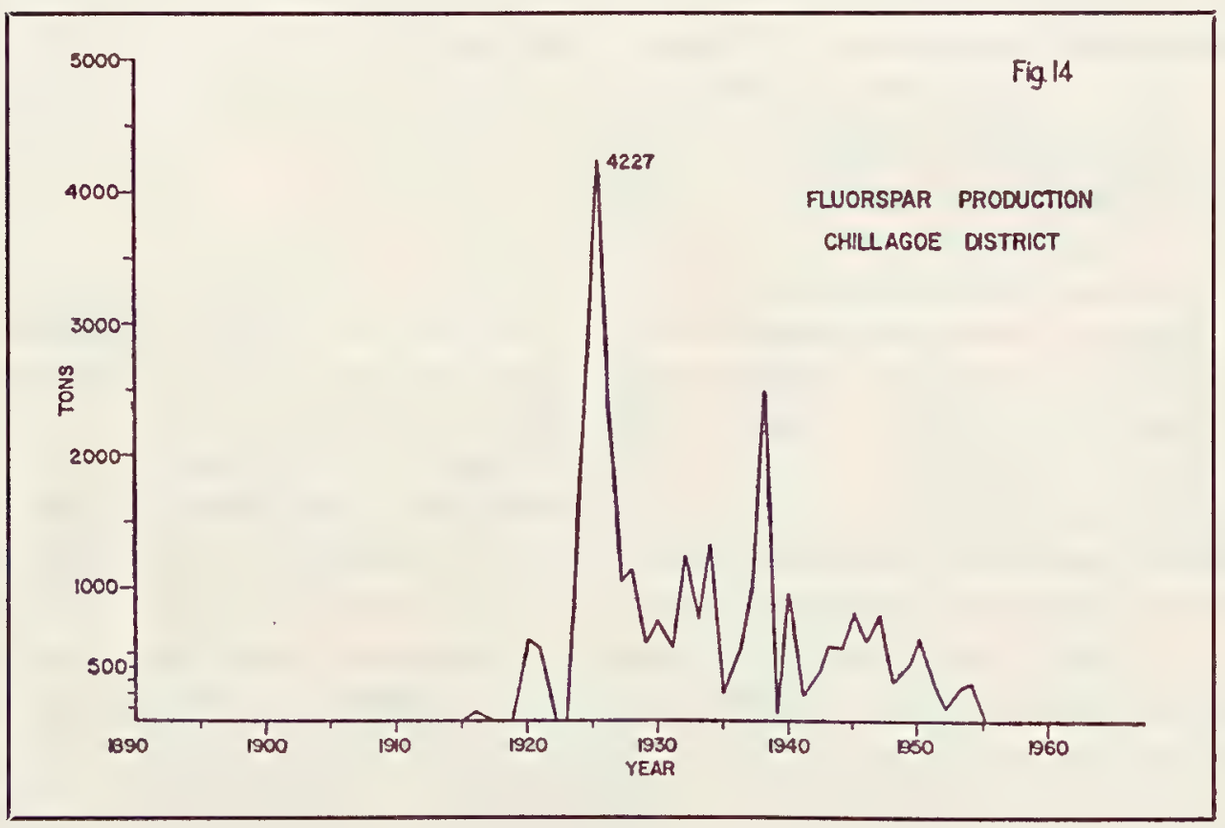
Jensen (1941) mentioned the presence of auriferous greisen lodes in the Dargalong Metamorphics within the fluorspar-producing belt west and south of Mungana, and, drawing a parallel with the Fluorspar area, saw a reasonable chance that gold could be mined economically from the Dargalong Metamorphics. The gold occurs, as in the Fluorspar area, in rich patches in kaolinitic material formed at the intersections of greisen veins and thin quartz-fluorspar leaders.

The only mine worked for gold in the Chillagoe limestone belt was the *Lucky Tree* (Reid, 1932a; Morton, 1935b), situated in an alluvial plain at about 14 miles from Chillagoe and 7 miles north-west of Almaden. The ore occurred as pipes in metamorphosed limestone and contained copper, lead, and zinc minerals contaminated by some bismuth impurities. The gold content was not

high at the surface (15 dwt per ton were reported from one of the samples), but seemed to increase in depth. No figures are known, but production must have been very insignificant.

Fluorspar

The Chillagoe Gold and Mineral Field has been Queensland's largest producer of fluorspar. Many of the mines are in the area covered by this Bulletin; others are in the (Rocky) Tate River district. Production started in 1917 with the shipment to New Caledonia of 20 tons from the Mistake mine (51, e).



Although several of the lodes probably still contain fair quantities of good-grade fluorspar, and further lodes probably await discovery, the mines are all closed owing to generally low prices and the competition of fluorspar produced by cheap labour abroad. To compete under the present circumstances the Queensland mines would have to be worked at lower cost, and the ore from them would have to be transported at unrealistically low costs. In 1958 the only workings that showed any signs of recent activity were the Mistake mine and small deposits south of Almaden; the main production in that year came from the Tate River and Bullock Creek areas, south of the region discussed in this paper.

Fluorspar occurs in fissure lodes either in the Permo-Carboniferous granites or in the Dargalong Metamorphics, and is in either case probably introduced by the youngest and most acid phase of the Permo-Carboniferous granites (Elizabeth

Creek Granite). This explains why no fluorspar has been found in the Chillagoe limestone areas: these are intruded by the less acid and slightly older adamellites and granodiorites (Herbert River and Almaden Granites).

The mineral, as a rule, occurs in isolated lenses or in series of lenses, or in sporadic bunches and patches in otherwise barren veins of quartz and brecciated country rock. White, opaque quartz, locally termed 'Bone' because of its coralline or bony appearance, forms the footwall, and in many places, also the hangingwall of the shoots. The fluorspar is generally clear and white, but also green, purple, and brownish. Both fluorspar and quartz occur in more than one generation: brecciated fluorspar has been cemented by later fluorspar, and quartz and chalcedony have replaced fluorspar along cleavage fractures, or have—in rare places—completely replaced octahedral fluorspar crystals.

Within the area under discussion the main fluorspar centres are:

1—a group west of Mungana (15);

2—north and south of the Dargalong lead mines (18, 19, 20);

3—the Fluorspar group (30, h, k, l);

4—workings south-west of Almaden;

5—the Mistake mine, Emuford district (51, e).

Mungana fluorspar mines

(Ridgway, 1945)

Fluorspar was first mined here in 1924 from workings along the original 'Fluoric' line of lodes, later known as the Relief, Midway, and Peter Pan claims (15, f.g.h). This is a large lode system composed of sub-parallel overlapping, and branching fissures, cropping out intermittently over a distance of four miles and trending north-west. The host rocks are the Dargalong Metamorphics, which range from predominantly mica schist in the north-west to granitic gneiss in the south-east.

The best known workings on this lode system are the Condon-Ogilvie, Runner Away, Muldiva, Peter Pan, Midway, Relief, and Pharlap. Other mines in the general area but not forming part of the Fluoric lode system are the Curley's, Dead Dog, and Simpson. Most of these workings have been described and illustrated with plans by Ridgway (1945).

The Pharlap (15, j) is at the southern end of the Fluoric lode system 6.8 miles by road south-south-west of Mungana. The lode strikes 295° in granulite, and dips almost vertically south-west. Workings comprise 6 shafts (the deepest reaching 105 feet), open cut, trenches, and costeans over a distance of some 700 feet. Since Ridgway's examination (1945) work has extended a hundred yards farther north to include two shafts, the deeper of which reached 65 feet. In the bottom of this shaft the fluorspar vein was 5 feet wide. Average grade of ore was 84 percent CaF_2 but water in these workings was a problem.

Much ore was extracted by stoping from the main lode, which was about 7 to 10 feet wide.

The *Relief* (15, h) lies about six miles south-west of Mungana, and on the Fluoric lode system. The lode here is much branched, and the main lode is the most easterly of the branches. According to local information some high-grade ore has been won; the deepest shaft is reported to be 100 feet deep, and has a 6-foot wide 'bony' fluorspar lode showing at the bottom. Most of the workings do not extend below 60 feet. Open-cutting has been almost continuous over 450 feet, but during the last few years the only work done has been the sinking of a 9-foot pit.

Immediately north-west of, and adjacent to, the Relief is the *Midway* claim (15, g), which comprises shafts, 26 and 56 feet deep, and trenches. From the deeper shaft 60 tons of 90 percent fluorspar was won. A vein 2 feet wide was seen in the 26-foot-deep shaft. Ore from the Midway averaged 88 per-cent CaF_2.

The *Invicta* has two shafts 25 and 26 feet deep, and is situated north of the Peter Pan. A vein of fluorspar 6 inches wide is present in the bottom of the shafts.

The *Peter Pan* workings (15, f) adjoin the Midway claim. In a now inaccessible timbered shaft 33 feet deep the fluorspar vein was 3 feet 6 inches wide. West of this a shaft 60 feet deep was sunk, and bottomed on 5 feet of fluorspar. 'Bone' quartz forms the footwall and granitic gneiss the hangingwall. Workings indicate a lens some 250 feet long.

In the same lode system and about three-quarters of a mile north-west of the Peter Pan lies the *Muldiva* (15, e) with workings spread out over 100 feet along the 3-foot wide lode. The deepest shaft was 50 feet.

The *Runner Away,* or *Soldier Bill* (15, d), lies about one quarter of a mile north-west of the Muldiva. Two shallow open cuts opened up this lode for a distance of 58 feet. The 3-foot-wide vein carried 9 inches of clean fluorspar. No development has been carried out since 1945.

About three-quarters of a mile north-west of the Runner Away, the main *Condon - Ogilvie* workings (15, c) occur in mica schist striking 305°. Workings on the other three branches are only shallow. From the main line of lode some clear, high-grade ore (95 percent) has been won. Soft ground made the western branch of the lode difficult to work. Two ore-shoots were mined over stretches of 70 and 140 feet. Three shafts have been sunk, and more than 1500 tons of good-grade ore have been taken out, according to local inhabitants.

Simpson's workings (15, i) are situated on Harry's Creek, a tributary of Wandoo Creek, about 3 miles south-west from the Relief and Midway workings on Muldiva Creek. The lode is very distinct, and occupies a fissure striking north-west and dipping steeply south-west in the Dargalon Metamorphics. It

has been worked over a distance of 1100 feet. The average width of the fluorspar was 2 to 3 feet, and the average grade of ore was 85 percent CaF_2. The deepest working was a 70-foot shaft.

Curley's mine (15, a) comprised shafts and trenches over a length of 450 feet in granulite and gneiss with amphibolite intrusions. The deposit lies about nine miles by road west of Mungana. The lode strikes 200°, dips 85° west, and is about 3 feet wide. 'Bone' quartz occurs on the footwall and country rock in the hangingwall. Some of the fluorspar sold assayed up to 92 percent CaF_2; average grade was 88 percent. The main period of production was around 1937.

Other localities in the Mungana area from which fluorspar has been won include the Dead Dog Creek, where trenches on a 15-inch vein have yielded 9 tons of ore, and an occurrence near Windy Gully on the Wandoo track west of Muldiva.

Dargalong area (18, 19, 20)

(Ridgway, 1945)

In the Dargalong area the most important workings are those of the *Jackson* group (20), about four miles south-east from the Pharlap, and virtually on the projected continuation of the Fluoric lode system. The group consists of a long line of workings along a 'bone'-type quartz lode which can be traced—with some breaks—through muscovite granite. The deposit lies about nine road miles south-west of Chillagoe. Access is by the Bolwarra road and thence across country for about three miles. The lode strikes along Little Dargalong Creek at 330°, and dips nearly vertically. It consists of two roughly parallel veins, the more easterly of which has been worked over 800 feet, the other over 135 feet. Fluorspar veins are up to 6 feet wide, bounded by quartz and chalcedony. The fluorspar is clear and commonly contains 85 percent CaF_2, or more. Workings include trenches, costeans, and shafts, the deepest being 90 feet. The most recent lease of this property was taken up in 1958 by Messrs. Black and Fitzgerald.

Less than half a mile south of the Jackson two fluorspar veins with some branchings were opened up over stretches of 210 feet and 25 feet.

About 1 mile east of the Pharlap mine, and on Muldiva Creek, is a fluorspar mine which was probably known as Stewart's. Fluorspar occurs in a fissure lode in granulite, mica schist, and gneiss in the vicinity of augen gneiss and intrusive andesite. The lode strikes 320° and dips 75° south-west. Visible workings extend over 300 feet, and have exposed a vein, 12 inches wide, of clear, white, and brownish fluorite with grades ranging up to 86 percent CaF_2.

Shaw's workings lie four miles east of the Pharlap mine on Muldiva Creek. The lode is in gneiss, strikes 320°, and has been worked over a length of 150 feet.

Approximately 1½ miles south-south-west of the Jubilee mine, Dargalong, a trench 10 feet long has exposed a fluorspar-quartz vein striking 355°.

Fluorspar group (30, h, k, l)
(Ridgway, 1945)

The Fluorspar group of workings includes a number of gold mines and only one fluorspar lode of any significance: the *Perseverance* (30, h). Mining from the Perseverance lode, which is situated on the bank of Crooked Creek about 7 miles west by north of Almaden, was first reported in 1921, but records of production were not kept until 1923. The mine was worked from 1924 to 1928 by the 'Fluorspar Limited' company, and produced 7300 tons of ore during that period. There was some sporadic activity after 1944.

The lode is a fissure vein in hornblende-biotite granodiorite; it strikes east-north-east, dips nearly vertically south-east, and contains almost continuous lenses of fluorspar enveloped in 'bone' quartz. Workings, which include shafts, trenches, and open cuts, extend over a length of 1850 feet, though concentrated within a stretch of 1000 feet. The maximum width of the lode is 7 feet, the maximum depth worked rarely exceeds 50 feet. One shaft reached a depth of 100 feet, showing a fluorspar vein 2 feet wide at the bottom. The lode branches at its eastern end. Ridgway (1945), assuming the depth of the lode to be proportionate to its length, estimated that some 30,000 tons of ore might be available down to a depth of several hundred feet.

Samples assayed at the Chillagoe smelters in 1923 gave the following results:

	percent
average clean fluorspar	97.30 CaF_2
	1.11 $CaCO_3$
violet-tinted fluorspar	95.25 CaF_2
	1.64 $CaCO_3$
green-tinted fluorspar	96.06 CaF_2
	1.56 $CaCO_3$

Apart from the Perseverance, there are some small fluorspar veins about a mile east of the mine, and half a mile south-west of the Federal Flag gold mine.

Workings south-west of Almaden

The *Eaglehawk* mine (37, a) was re-opened at the end of 1951 by W. Black, and was worked until 1954. The lode, 9.3 miles by road south-west of Almaden, comprises three veins of colourless to green fluorspar separated by bone quartz striking 205° and dipping nearly vertically in hornblende-biotite adamellite.

The workings are shallow (up to 46 feet deep) and extend only 160 feet along the lode. The greatest vein width is about 1 foot. A State Government assay of a chip sample taken across the vein in 1958 gave:

	percent
CaF_2	69.0
SiO_2	23.7
$CaCO_3$	0.5
Fe_2O_3	0.7

About 1 mile east of the Eaglehawk, two small lodes with fluorspar veins 2 to 4 feet wide have been worked by Black, Fitzgerald, and others.

Emuford area

The *Mistake* mine (Saint-Smith, 1917b; Ridgway, 1945), a mixed wolfram-fluorspar mine, lies about eight miles by road south-east of Petford, and was the first fluorspar producer in the Chillagoe district. In 1920 and 1921 the 'Industrial Pigment Co. Ltd' worked the mine for a yield of 1140 tons of fluorspar.

The lode occupies a vertical fissure in granite and greisen, and strikes east of north. The granite is crushed near the lode, which is possible evidence of part of the important fault-line that separates the Mount Garnet Formation from the Hodgkinson Formation farther to the north.

The older development work has been described by Saint-Smith (1917b). The lode reached a width of 9 feet, and contained fluorspar shoots up to 6 feet thick, and averaging 3 feet. The best wolfram ore appears to have occurred in shoots in the middle of the orebody where finely granular wolframite transgressed the fluorspar in stringers. The lode was opened up over a distance of 500 feet at the surface, and, at the 160-foot level, workings extended for 400 feet along the lode. These workings are now inaccessible.

After having been idle for several years the mine was re-opened in 1958 by Black and McEwan, who sank a vertical shaft to 44 feet on the northern extension of the lode. From this level they had driven, at the time of inspection, 87 feet along the lode in fluorspar ore with a width of up to 4½ feet. Wolframite is fine-grained, and chiefly concentrated on the western side of the drive. There is some irregular quartz veining. Fracture planes filled with crushed fluorite and ferruginous clay commonly run parallel to the lode. At the 30-foot level the operators drove north for at least 25 feet, extracting fluorspar from veins up to 5 feet wide.

Iron

Contact-metasomatic iron deposits are common in the Chillagoe Formation along the contact zones of the granite intrusions. Most are small and discontinuous, but some have been worked to provide flux material for the Chillagoe smelters. The deposits are most abundant in the limestone members of the

formation, and are usually described as 'ironstone', a term describing any lode with an appreciable iron content, though such lodes are commonly highly siliceous. In the richer 'ironstones' magnetite and hematite are generally the chief iron minerals, and are commonly associated with garnet, which, in places, predominates over the iron minerals. In some deposits, copper and lead minerals were present in sufficient quantities to be worked, as in the 'ironstone' breccias at the Harper (27, f) and at Redcap (22, a-b).

Mount Lucy (34) (Dunstan, 1905c, 1906) is the only iron deposit of any importance in the Chillagoe district; it was a regular producer of flux ore for the Chillagoe smelters. The upper part of a low hill, 150 feet high, and about three miles west of Almaden on the Chillagoe-Almaden road, is largely composed of a magnetite-hematite mixture with associated garnet. Granite crops out on all sides of the deposit, which is about 700 feet long by 50 feet wide, and has a vertical extent of about 50 feet. Workings consist of a number of open cuts on the higher-grade portions. The total recorded production has been 45,344 tons, which represents roughly 58 percent of the recorded output of the Chillagoe district. In 1905 Dunstan estimated the reserves at 350,000 tons.

The magnetite-hematite is separated from the granite in many places by a garnet skarn-rock. Dunstan ascribed the ironstone to surface weathering of garnet; Denmead (1934d) later came to a similar conclusion for magnetite-hematite ore in the Calcifer area.

An assay of Mount Lucy iron ore gave the following values (Dunstan, 1906):

	percent
Ferrous oxide	6.81
Ferric oxide	90.30
Manganese oxide	0.60
Alumina	1.22
Silica	0.57
Phosphorus	nil
Tungstic acid	nil
	99.50

Many of the other ironstone deposits in the Chillagoe district were worked for associated copper and lead, but some in addition yielded flux ore. The best-known of these were the *Ti-tree* (26, g), the *Boomerang* (27 c), and the *Hobson* (27, d).

Denmead (1934d), after examining the ironstone outcrops at Calcifer, concluded that they were surface concentrations of an original garnet-magnetite mixture, because in all shafts the iron ore became disseminated or disappeared at fairly shallow depth.

Lime

One of the predominant lithological units in the Chillagoe Formation is limestone. It occurs interbedded with chert, quartz greywacke, and siltstone in a north-north-west trending belt from near Almaden to the Walsh River (and beyond), a distance of some 35 miles within the boundaries of the area mapped. The belt has a maximum width of about four miles. The limestone, normally light grey and finely crystalline, is coarsely recrystallized to a white, soft marble, or to calc-silicate hornfelses where the limestone was impure, around granite intrusions. Most of the limestone quarried has been used for chemical and agricultural purposes: the sugar-cane districts of Cairns and Innisfail consume much of the product. In the past the lime was also used as a flux in the smelters.

The main deposit is at *Ootann* (43), 7 miles south of Almaden, and is the only centre in the Chillagoe district producing limestone at present. Limestone is quarried from bluffs forming part of a large roof pendant block of sediments in granite. Reserves are very large, and the leases—Crotty No. 1 and Crotty No. 2—are well situated here, because they are alongside the Cairns-Forsayth railway, and are in an area not depleted of wood.

Massive limestone is worked for burned lime, and coarsely crystalline calcite for crushed lime. The colour of the rock ranges from white to grey, pink, blue grey, and cream; veins of coarse calcite and siderite and some silica are present. The calcium carbonate content is generally about 97 percent; iron oxide ranges up to 1.7 percent, and the silica content is low. A calcium carbonate content of not less than 90 percent is required for marketing.

After blasting, the coarse calcite is hand-sorted for fine grinding in a ball mill, and is subsequently packed and shipped in 1 cwt bags. In 1958 production of crushed lime for agricultural purposes was at the rate of 30 tons a day. The massive limestone is broken in a jaw crusher into fragments not more than 4 inches across, and is then burnt in a roasting kiln. The burnt product is bagged in 204-pound bags. The output of burnt lime averaged about 30 tons per week in 1958, and is used mainly in the refinement of sugar.

During the old mining days limestone was quarried as a flux mineral from several quarries near Mungana, Chillagoe, and Calcifer, and Messrs Sycamore and Demchok produced burnt lime near the Griffith mine only a few years ago.

'Earthy lime' (travertine), derived by weathering from the Chillagoe limestones, has been deposited in gullies and depressions, and is used in agriculture. The Mungana Lime Supply Co. for several years worked a deposit in a gully several hundred yards north of Rookwood Homestead; the workings measured 54 feet by 25 feet and had a maximum depth of 8 feet. The lime is soft and earthy and contains small amounts of scattered limestone nodules near the surface.

About 1 mile north of Rookwood, on the Wrotham Park road, the same company worked an open cut measuring 43 feet by 24 feet, and with a depth of about 6 feet.

A third deposit, *O'Shea's Earthy Lime* (33), is situated four miles north-west of Almaden on the Manipota track near Four Mile Creek. The pit here measures about 35 feet by 35 feet by 5 feet deep.

'Iceland Spar' (Morton, 1944a) in the form of coarse calcite crystals up to 9 inches across, occurs in veins near Deep Creek, 1 mile from Rookwood Homestead. The crystals are marred by cleavage planes and twinning lamellae, and their transparency is not perfect, so that they are not suitable for use in the optical industry.

Deposits of coarse white marble along granite contacts offer some economic potential as building and monumental stone. The marble has few impurities, and has been used locally for tombstones.

Minor Mineral Occurrences

Several minerals other than those described in the foregoing pages are known to be present in the district, but their occurrences are uneconomic and of mineralogical interest only.

Antimony — Only a few occurrences have been recorded from the area. A hundred yards north of the Mistake fluorspar mine (51, e) several prospect holes sunk on a hill on well-jointed granite and greisen have revealed stibnite and cervantite in two thin quartz veins 8 inches and 2 inches wide, and striking 035°. Stibnite has also been recorded from the deeper workings of the old Queen lease at Dargalong. Jensen (1941) mentioned antimony lodes at Scardon's Camp (45).

Clay — Bricks used in the Chillagoe smelter stack and buildings were made from local clays from the limestone areas around Chillagoe. One such deposit was situated about two miles from the town, and was worked to a depth of 8 feet. No investigations have been made of the clay reserves; there is no local demand for bricks, and, even if good clay reserves exist, brick-making without a local market is not an economic proposition.

Coal — Coal was found in 1910 by a Mr Conroy three miles north-east of Koorboora, in a very impure and small deposit (47, t) (Q.G.M.J., 1910). The deposit is one mile north of the Chillagoe railway and its discovery aroused great interest; mining was at a peak at the time and the Chillagoe smelters needed considerable quantities of fuel. At the instigation of the Chillagoe Railway and Mines Ltd several underlie shafts were sunk, but the coal and carbonaceous shale proved to be not of commercial value.

The coal is associated with flaggy sandstone and grey waterlaid tuff which occur near, and form part of, the base of the Featherbed Volcanics. The out-

crop is of very limited extent and represents a small depositional area only. A thickness of 6 to 8 feet has been reported for the coal bed. The dips in the sediments are less than 5°. The coal is soft and crumbly and probably has an extremely high ash content. Samples taken for micropalaeontological investigations in 1961 proved devoid of spores and pollen, which were presumably destroyed by the heat of overlying extrusions.

Cobalt (Jensen, 1941) — The only cobalt known from the Chillagoe district occurs in the *Cambourne* lode (22, e), south-west of Mount Redcap. Two parallel lodes, each 6 to 8 feet wide and approximately 130 feet apart, are separated by fine-grained basalt and contain two shafts with a maximum depth of 150 feet. The East Cambourne lode dips to the south-west, the Main Cambourne lode dips steeply to the north-east. They are lined by garnet replacement rock through which runs a core of gossanous 'ironstone'. In both lodes cobalt occurs over about 100 feet as cobaltite associated with chalcopyrite and some chalcocite, and a little erythrite at the surface.

Although some rich patches and specimens were found, the bulk of the ore is low-grade and not of commercial value. Grab samples taken at random from the Cambourne lode by Shaw and Sycamore in 1953 showed no more than a trace of cobalt. Metal Explorations drilled the lode in 1956, but the results were discouraging.

Manganese — At Redcap, manganese 'wad', manganiferous 'ironstone', and nodular manganese ore occupy a large part of the lode exposure. Cerussite penetrates this manganiferous material. The MnO content is normally about 15 percent, and there are no indications that the deposit has any economic possibilities.

An isolated manganiferous outcrop (55) was noted in a railway cutting 1 mile west of Lappa Junction, near the Petford-Almaden road. The ore is highly siliceous and contains a psilomelane-type mineral associated with a joint-plane in rhyolite near its contact with the Palaeozoic sediments. A dyke of hornblende-quartz diorite is exposed nearby. The deposit is small and has no economic significance.

About a quarter of a mile north-west of Mungana, an old shaft (63) in highly manganiferous 'ironstone' shows copper staining, but was probably sunk for gold.

'Pyrolusite' has been identified in the Otho lode, south-east of Chillagoe (between 26, b and e).

Mica (Owen, 1942; Morton & Ridgway, 1944a) — The pegmatites in the Dargalong Metamorphics carry muscovite, but only in the *Mount Kitchin* area (3) has the mica been segregated in books large enough to be of any interest.

The Mount Kitchin mica prospects are located near Barker's Creek 30 miles west of Chillagoe and 11 miles south-west of Cardross. Mica was noted

here in 1915, and in 1942 six leases were held. The quartz-feldspar-mica pegmatites occur in gneiss and granulite of the Dargalong Metamorphics as dykes and patches with circular outline, which at first were thought to be pipe-like bodies. Subsequent investigation, however, showed the 'pipes' to be pockets and segregations, cutting out at shallow depth, and the Mount Kitchin deposits were therefore written off as a commercial prospect.

The mica occurs in books up to 1 foot square. Much of the surface material is weathered and soft, warped, fractured, and stained, but good quality mica, free from inclusions and only little stained, has also been taken from this deposit. The mica seems to be most often associated with the quartz in the pegmatites.

The workings are concentrated in a zone striking about 070°, and include open cuts and shallow vertical and inclined shafts; the deepest shaft went down to 33 feet on the old Wonder Lease. In 1941 the area produced about 2 cwt of roughly trimmed mica; in 1942 the leases were taken over as a war-time measure by the Controller of Mineral Production; the inadequate dimensions of the deposits were recognized, and there has been no subsequent production.

In 1891 leases to work mica were taken up in the Wandoo area, but no details are known. Jack (1898) noted mica at the head of Wandoo Creek, but gave no details.

Quartz — Appreciable tonnages of fine-grained, sugary, very pure quartzite from the *Silica Quarry* (26, b), about half a mile east of Chillagoe, have been used as metallurgical flux at the Chillagoe smelters. The outcrop extends along the railway line for several hundred yards. The quartzite is possibly a completely silicified limestone, in view of its sugary texture and extreme purity.

The only commercial quartz crystals produced in Queensland have come from a vug in the wolframite pipes at the *Enterprise* mine, Wolfram Camp (60, f). Dumps at the mine supplied several tons of quartz crystals, of which only 24 pounds were accepted as suitable for piezo-electric uses. The vug that contained the quartz crystals was about 300 feet below the surface, and there are probably others present in the wolframite pipes.

Titanium — Rutile in lode form occurs in two areas in the Chillagoe district. Lode rutile was first reported in 1945 from the Muldiva Creek area in schist, augen gneiss, and quartzite of the Dargalong Metamorphics, intruded by irregular pegmatitic and aplitic veins. Rutile, in the form of subangular to angular grains, occurs in thin bands up to half an inch thick in an equigranular quartz-feldspar rock. Some mica is visible along the foliation planes. Clear quartz veins run parallel to the foliation and rutile seams, giving the rock a gneissic appearance. A basic dyke striking north-east cuts the 'lode'. Weathered parts of the rocks have a somewhat saccharoidal texture, and are firm, yet crumbly when struck. The 'lode' strikes 290° and dips 60° south-west, and is contained within an area of about 600 feet by 90 feet. The middle layer of the 'orebody' carries

the highest concentration of rutile—about 40 percent—and is up to 9 inches thick.

In 1953 Dowsett Engineering (Aust.) Pty Ltd took up a lease on the deposit. Eleven prospecting holes were sunk. In 1955, 6 tons, 8 cwt of ore were treated at the Great Northern Battery, Herberton, for a yield of 1 ton, 13 cwt, 2 qr of concentrate, reputed to contain 86 percent titanium oxide.

The tonnage available seems too small to attract commercial interest, and from surface observations the chances of locating extensions of the lode or other deposits appear remote.

A lease application was made for rutile mining in the Lappa area in 1953 —the Patrick No. 2. No further details are known.

Uranium — The areas indicated on the map of radioactive anomalies in the Chillagoe-Einasleigh-Gilberton region (BMR, 1955), and some of those noted during the 1958 magnetometer and scintillometer aerial survey, were investigated on the ground by means of geiger counter traverses, without success.

For some time a uranium prospecting permit was held over a section of the Featherbed Volcanics north-east of Almaden. Results of prospecting are not known.

An unidentified uranium mineral associated with wolframite and tungstic ochre in a quartz lode in greisen has been recorded from the Tommy Burns tin mine.

The occurrence 'at a wolfram mine at Lappa' of torbernite associated with wolframite, molybdenite, and bismuth in a quartz-topaz-hematite lode in granite also appears in records.

CONCLUSIONS AND RECOMMENDATIONS

The rapid intensive development of the Chillagoe Field is a thing of the past, and is not likely to be repeated. The easy-to-find surface deposits of the copper and lead contact lodes have probably all been discovered, and most of their richer parts have been mined out. Single discoveries may still be made, but would not lead to a large-scale re-opening of the field. Several orebodies are undoubtedly still present at depth, but they would be difficult to find and assess, and the irregularity and comparatively small size of the contact deposits in the area generally makes them not very attractive at present. However, should further exploration be contemplated in the future, then attention should be given to the Zillmanton and the Cardross areas as the first logical test targets: Zillmanton, because geophysical work has pin-pointed a possible ore-bearing zone 1½ miles long, with well-defined anomalies, and with alluvium-covered stretches that have never been adequately prospected; furthermore, a drill-hole in Reid's section is reported to have intersected ore assaying 3 percent copper between the 260 and 361-foot levels; Cardross, because drill-holes have shown

4 to 10-foot sections of 10 to 20 percent ore, a zone of secondary enrichment is commonly well developed, the grade of the primary ore appears to lie within a range of 2 to 6 percent copper, and (low-grade) lodes have been reported to be consistent and extensive. However, results of testing of Cardross by Broken Hill South Ltd in 1962/63 did not bear out the optimistic expectations.

Hopes for the presence of large tonnages of low-grade disseminated copper ore at Ruddygore have not been borne out by Mount Isa Mines Ltd's test-drilling in 1960, although it does appear that this programme by no means dispelled all prospects here: core recovery was unsatisfactory, and results were not exhaustive. Some testing of the large bodies of altered ferruginous granodiorite found by Dallwitz and Morgan (pers. comm.) in the area east and north-east of Ruddygore in 1961 may be warranted.

The largest known reserves of low-grade copper ore, some 350,000 tons of flux ore, are left at the Ti-tree deposit.

A revival of wolframite and molybdenite mining on a large scale seems improbable: most pipes have probably been found, and their upper parts have been depleted. But, although the pipes are too small and difficult to locate for mining at any scale at depth, there remains a possibility that the disseminated type of ore might exist in sufficient quantity to make it a mining proposition.

Although tin mineralization in the Chillagoe district has not reached the same intensity as in the neighbouring Herberton area, there is scope for surprises, as the example of the Dover Castle mine has shown. This mine had been considered 'dead' when the shaft was at a depth of some 300 feet, but subsequent sinking opened up a further rich ore-shoot which has since been followed down to about 560 feet (1961) with no decline in values. Though this mine is of a type somewhat different from the other tin deposits in the district—it occurs in volcanics, instead of in sediments, and the lode is more sharply defined than usual—the example shows that local beliefs are not a reliable measuring stick, and it is conceivable that testing at depth in the Koorboora and Sunnymount areas may prove successful in places.

Fluorspar appears to be a mineral with a promising future. There is an ever-increasing world demand, particularly in the chemical industry—which, in the U.S.A., for instance, consumed 200 percent more fluorspar in 1957 than in 1950. Several of the lodes in the Chillagoe district contain considerable reserves, and, where the required 97 percent CaF_2 grade for acid-grade fluorspar is not present, lower-grade and disseminated ore can be beneficiated by flotation. However, to compete with imported ore from low-wage countries, costs would have to be reduced all round: the only obvious way in which this might be done is by a large-scale open-pitting operation, for which the fluorspar veins are not suited, although it is not inconceivable that the right circumstances might exist in the area.

At the time of writing a diamond drilling programme to prove fluorspar reserves was scheduled by the Queensland Department of Mines.

The once-significant minerals of the Chillagoe Field may not be mined again to any extent, but the area may still have prospects in minerals which held no interest in its hey-day. A widening industrial demand offers attractive prices for minerals which would not have been sought in the most active days of the area, yet the geological setting is right for some of them. An example is beryl, and the other minerals of beryllium. The metal commonly occurs in contact-metasomatic skarn rocks, in pegmatites, in high-temperature quartz veins, and in greisens; minerals commonly associated are fluorite (which adds to the attraction of the fluorspar lodes), topaz, wolframite, molybdenite, magnetite, and a variety of skarn minerals; and beryllium is often associated with alkalic granites. All these mineralogical and geological conditions are widely represented in the Chillagoe district, which therefore should be considered a favourable prospecting area for beryllium, particularly as improving extraction techniques may dispense with the necessity for the hand-sorting that favours low-wage producers.

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APPENDIX 1

INDEX TO MINE LOCALITY MAP (See plate 13)

Reference No.	Atherton RAAF, 1951 Run & Photo No.	Product	Name of Mine or Prospect
1	1/5029	Cu	?
2	2/5105	„	?
3	3/5113	Mica	Mount Kitchin
4	1/5029	Cu	Arizona group of workings
5	1/5031	Cu (Au, Pb, Ag)	Cardross - Arbouin group:
a			Chieftain
b			Keppoch
c			Caledonia
d			Klondyke
e			Clansman
6	2/5105	Cu	Spaniard
7	„	„	Mountain Maid
8	1/5035	„	Buchanan's ?
9	2/5101	Ti	Muldiva Creek Lode Rutile
10	2/5099	Au	Mount Wandoo mines
11	1/5037	Ca (earth)	Rookwood
12	„	„ „	„
13	2/5099	Cu	Jubilee
14	„	„	Red Hill
15		F	Mungana Fluorspar mines:
a	2/5099		Curleys
b	„		Dead Dog
c	„		Condon - Ogilvie
d	„		Runner Away
e	„		Muldiva
f	„		Peter Pan
g	„		Midway
h	„		Relief
i	3/5119		Simpsons
j	3/5119		Pharlap
16	3/5121	Cu	Mount Delaney
17	„	„	?
18	3/5121	F	?
19	4/5179	„	?
20	3/5121	„	Jackson Group:
a			Jackson
21	3/5121	Pb, Ag, (Cu)	Dargalong Group:
a			Jubilee
22	2/5097	Cu, Pb	Redcap Group:
a			Redcap
b			Queenslander
c			Morrison
d			Tarantula, Victoria
e	2/5097	Cu	Belgravia, Puppet
f	„	Cu, Co	Cambourne
g	„	„	McIlwraith and Penzance
h	„	„	Nellie
23	„	Ag, Pb, Cu	Mungana Mines:
a			Girofla
b			Lady Jane
c			Dorothy
d			Moffatt's
e			Red Dome
f			Magazine Face
g			Nordville
h			Calumet
i			Griffiths

Reference No.	Atherton RAAF, 1951 Run & Photo No.	Product	Name of Mine or Prospect
24	2/5095	Cu	Zillmanton:
a			Shannon shafts
b			Zillmanton shafts
25	2/5093	„	Ruddygore
26	3/5125	Pb, Ag, Cu	Chillagoe Mines:
a		Pb, Ag	Chillagoe Consols
b		Si	Silica Quarry
c		Cu	Atherton
d		Pb, Ag, Cu	Christmas Gift
e		„ „ „	Lyonite Hills
f		Pb, Cu	?
g		Cu	Ti-tree
h		Pb, Ag, Cu	Upper Hensey (west end)
i		„ „ „	Big Hensey (west end)
j		„ „ „	Big Hensey (east end)
k		„ „ „	Fortunata
27	3/5125		Calcifer group:
a		Pb, Ag, Cu	?
b		Cu	?
c		„	Boomerang
d		„	Hobson
e		Cu, Ag	Five Chain Bend
f		Cu	Harper
28	3/5125	„	(small workings)
29	4/5175	„	?
30	4/5173		Fluorspar Group:
a		Au	Leg Theory
b		„	Hikers
c		„	Ironbark
d		„	Blue Ensign
e		„	Retchfords (Golden King)
f	4/5173	Au	New Zealand Flag
g		„	?
h		F	Perseverance
i		Au	Australian Flag
j		Cu	Gibraltar
k		F	?
l		„	?
m		Au	Federal Flag
31	5/5137	Pb, Ag, Cu	Maniopota workings
32	„	Cu	?
33	„	Co (earth)	O'Sheas
34	„	Fe	Mount Lucy
35	5/5135		Muldiva Mines:
a		Cu	Muldiva
		Cu, Pb, Zn	Eclipse
b		Pb, Ag, Cu	Paisley
36	5/5235	F	?
37	6/5187	F	Fluorspar workings, Almaden
a			Eaglehawk
38	7/5029		Khartoum District:
a		W	Mount Riddell
b		Mo	Murrays
c		„	Ajax
d		„	Kitchener
39		Mo	(small workings)
40	7/5029	Pb, Cu	?
41	„	Cu	?
42	„	Pb, Cu	?
43	„	Ca	Crotty Nos. 1 & 2
44	„	Cu	David

Reference No.	Atherton RAAF, 1951 Run & Photo No.	Product	Name of Mine or Prospect
45	4/5171		Scardon's workings
a		W	Scardon"s Top Camp
b		W, Mo	Scardon's Bottom Camp
46	5/5139	Pb, Ag	Torpy's Crooked Creek Mine
47			Koorboora Mines:
a	6/5181	Sn	Bismarck Creek (alluvial)
b	,,	,,	?
c	,,	,,	?
d	,,	,,	?
e	,,	Pb, Ag	Bonzer Conroy's
f	,,	Sn	?
g	,,	,,	Southwick
h	,,	,,	Argo
i	,,	,,	Iolanthe ?
j	6/5181	Sn	Proserpine
k	,,	,,	Shakespeare
l	,,	,,	Try Again ?
m	,,	Sn, Pb, Ag	Tennyson
n	,,	,, ,, ,,	?
o	,,	Sn	Fair Play
p	,,	W	Neville, Mavis Bruce, Telegraph
q	7/5023	W	?
r	6/5181	Sn	Two Jacks
s	,,	,,	Dalnotter
t	,,	C	(minor occurrence)
48	7/5023	Sn	Sunnymount Group:
a			Kerosene Tin
b			O'Shea's Prospect
c			Prince Alfred
d			Cyclone
e			Cabbage Patch
f			Tommy Burns
g			Christmas Gift
h			New Years Gift
49	8/5076	W	Indicator
50	8/5078	Sn	(alluvial workings)
51			Emuford Group (part of):
a	7/5019	Sn	Chance
b	,,	W	Spotted Dog
c	,,	Cu	?
d	,,	Sn	?
e	,,	F, W	Mistake
f	,,	W	Gold Rod
g	,,	Sn, Cu	Brown Snake
h	,,	W	?
i	,,	W	Sydney
j	,,	W	?
k	,,	W, Cu	Mystery
l	,,	W	?
52	6/5177	Ag, Pb	Silver Spray
53	,,	Cu	Emerald Hill
54	6/5179	Sn	Mountain Maid
55	,,	Mn	(mineral occurrence)
56	5/5145	Pb, Cu	?
57	5/5145		Bamford Hill Mines:
a		W, Mo	Shady Corner
b		Mo	?
c		W, Mo, Bi	Sunny Corner
d		,, ,, ,,	Canberra
e		,, ,, ,,	Extended

Reference No.	Atherton RAAF, 1951 Run & Photo No.	Product	Name of Mine or Prospect
			Bamfield Hill Mines (Continued)
f		" " "	Haymaker
g		" " "	KY
h		" " "	Davis
i		" " "	Forget-Me-Not
j		" " "	Brandon
k		Mo	?
l		W, Mo, Bi	Gillian Bridge
m		" " "	Osbourne
n		" " "	Ferguson
o		" " "	Nelson's
p		" " "	Rose of Queensland
q		" " "	Rollinson
r		" " "	Winters
s		" " "	Plum Pudding
t		" " "	Ballarat
u		" " "	Tigers Tail
v		Sn	Federal
58	5/5143		Dover Castle Group:
a		Sn	King Midas
b		"	Dover Castle
c		Ag, Pb	Comstock
d		" "	Silver Bead
e		" "	Better Luck
f		Pb, Zn	?
g		Sn	Christmas Gift
59	4/5165	Mo, W	Eight Mile Mine (Petford)
60	2/5083		Wolfram Camp Mines:
a		W, Mo, Bi	Forget-Me-Not
b		" " "	Leisner
c		" " "	Larkin
d		" " "	Murphy
e		" " "	Harp of Erin
f		" " "	Enterprise
g		" " "	Victory
h		" " "	Finnigan
i		" " "	Avoca
j		" " "	Killarney
k		" " "	Nil Desperandum
l	2/5083	W, Mo, Bi	Pinwell
m		" " "	Mulligan
n		" " "	Tully
61	1/5050	W	Four Mile workings
62	"	Sn	Eight Mile mine
63	2/5097	Au, Mn, Cu	? (working at Mungana)

APPENDIX 2

MAPS, PLANS AND SECTIONS OF MINES ON THE ALMADEN, CHILLAGOE AND MUNGANA ONE-MILE SHEETS ON FILE AT THE GEOLOGICAL SURVEY OF QUEENSLAND OFFICE

PART 1

G.S.Q. Ref. No.	Area	Subject	Authority — Author or Owner	Scale (to 1")
1/7	Bamford	K.Y. workings, plans and projected sections	Geological Survey Office	20 ft.
„	„	Ferguson United plan	„ „ „	20 ft.
„	„	Plan showing positions of present workings (1953) based on plan by L. C. Ball	„ „ „	4 ch.
„	„	Northern United plan	„ „ „	20 ft.
„	„	Forget-me-not plan and sections (longit.)	„ „ „	20 ft.
„	„	Brandon plan and sections (longit.)	„ „ „	20 ft.
1	Chillagoe	Calcifer group of leases, plan	Chillagoe Railway & Mines Ltd.	8 ch.
2	„	„ „ „ „ „	„ „ „ „	8 ch.
3	„	Fortunata „ „ „ „	„ „ „ „	8 ch.
4	„	Mungana „ „ „ „	„ „ „ „	8 ch.
5	„	Otho „ „ „ „	„ „ „ „	8 ch.
6	„	Redcap		
7	„	Ruddygore „ „ „	„ „ „ „	8 ch.
9	„	Redcap grp., Mungana grp., Villmanton grp.,		
	„	Redcap grp., Mungana grp., Zillmanton grp., Calcifer grp., and Harper grp.	Chillagoe Gold and Min. Field (1940)	20 ch.
10	„	Chillago, Consols M.L. 14	Chillagoe State Smelters & Mines	30 ft.
12	„	Lady Jane section (longit.)	„ „ „ „	30 ft.
13	„	„ „ surface plan	Mungana (Chillagoe) Mg. Co. Ltd.	30 ft.
14	„	„ „ section	Chillagoe State Smelters & Mines	60 ft.
15	Chillagoe	Girofla section (longit.)	„ „ „ „	30 ft.
16	„	„ „ „	„ „ „ „	30 ft.
17	„	Calumet & No. 1 Shafts 24 M (1901) section (longit.)	Mungana (Chillagoe) Mg. Co. Ltd.	30 ft.
19	„	Queenslander 14 M plan	Chillagoe Railway & Mines Ltd.	30 ft.
20	„	Queenslander 14 M Section (longit.)	„ „ „ „	60 ft.
21	„	Nellie 5 M; work to 1905 plan	„ „ „ „	30 ft.

G.S.Q. Ref. No.	Area	Subject	Authority — Author or Owner	Scale (to 1")
22	„	McIlwraith and Penzance 7 M plan	Chillagoe Railway & Mines Ltd.	30 ft.
23	„	„ „ „ 7 M 1905 sections (longit. & cross)	„ „ „ „ „ „ „ „	30 ft.
24	„	South Penzance work to 1907 plan		30 ft.
25	„	Redcap ML 683 plan	Chillagoe State Smelters & Mines	30 ft.
26	„	Ruddygore 25 M plan	Chillagoe Railway & Mines Ltd.	30 ft.
27	„	„ 25 M cross sections	„ „ „ „	30 ft.
28	„	Zillmanton plan	„ „ „ „	4 ch.
29	„	Zillmanton-Reid Shaft section (longit.)	„ „ „ „	50 ft.
30	„	„ 23 M, 250 and 350 ft. level plan	„ „ „ „	100 ft.
31	„	„ 23 M, longit. section	„ „ „ „	100 ft.
32	„	„ 23 M, No. 1 Shaft cross section	„ „ „ „	50 ft.
33	„	„ 23 M, No. 2 Shaft cross section	„ „ „ „	50 ft.
34	„	„ 23 M, No. 2 Shaft „ „	„ „ „ „	50 ft.
35	„	„ 23 M, proposed No. 4 air shaft cross section	„ „ „ „	50 ft.
36	„	„ 22 M, Reid shaft cross section	„ „ „ „	50 ft.
37	„	„ 22 M, Reid shaft working plan	„ „ „ „	50 ft.
38	Chillagoe	Eclipse - Muldiva ML 30 (1912) plan	Chillagoe Railway & Mines Ltd.	30 ft.
41	„	Chillagoe - Mungana area, geological map	AGGSNA Q502 plate 2 sheet 1 Jensen 1941	40 ch.
41A	„	Fluorspar - Silica area, geological map	AGGSNA Q503 plate 2 sheet 2 Jensen 1941	40 ch.
42	„	Fluorspar grp. of mines, geological map	AGGSNA	500 ft.
43	„	Harper grp. of mines, geological map	„	200 ft.
44	„	Blue Ensign plan of mines, geological map	„	50 ft.
45	„	Otho, Hensey, Ti-tree group, geological map	„	600 ft.
46	„	Federal Flag, sketch plan	„	50 ft.
47	„	Redcap plan	„	8 ch.
48	„	Mungana plan	„	8 ch.
49	„	Zillmanton, geological map	„	1,200 ft. approx.
50	„	Mungana, Kaolin workings sketch plan	„	20 paces
51	„	Red Dome workings plan	„	50 ft.
1/15	„	Girofla Mine, plan of all levels, showing work to 1925	Chillagoe State Smelters & Mines	30 ft.
	„	Girofla Mine No. 2 Longit. section	„ „ „ „	30 ft.
	„	„ „ Plan 100 ft. level	„ „ „ „	30 ft.

G.S.Q. Ref. No.	Area	Subject	Authority — Author or Owner	Scale (to 1″)
	,,	,, ,, Plan 200 ft. level	Chillagoe State Smelters & Mines	30 ft.
	,,	,, ,, Plan 300 ft. level		30 ft.
	,,	,, ,, Plan 410 ft. level	,, ,, ,, ,,	30 ft.
	,,	,, ,, Plan 510 ft. level	,, ,, ,, ,,	30 ft.
	,,	,, ,, Plan 610 ft. level	,, ,, ,, ,,	30 ft.
1/15	Chillagoe	Girofla Mine, Plan 714 ft. level	,, ,, ,, ,,	30 ft.
	,,	,, ,, Section (cross)	Mungana (Chillagoe) Mg. Coy.	30 ft.
	,,	,, ,, Longit. Section	Chillagoe State Smelters & Mines	30 ft.
	,,	Queenslander 14 M, plan work done to 1908	New Chillagoe Rlwy. & Mines Ltd.	30 ft.
1/22	,,	Lady Jane Section	Mungana (Chillagoe) Mg. Coy.	30 ft.
	,,	,, ,, Plan and Section Workings in 1887	,, ,, ,, ,,	20 ft.
	,,	,, ,, 300 ft. level plan	,, ,, ,, ,,	30 ft.
	,,	,, ,, Plan showing work to 1926	Chillagoe State Smelters & Mines	30 ft.
	,,	,, ,, Plan to 1928	,, ,, ,, ,,	30 ft.
	,,	,, ,, Longit. Sectn. showing work to 1926	,, ,, ,, ,,	30 ft.
	,,	,, ,, Plan work done March 1910-March 1911 150, 210 and 420 levels	Mungana (Chillagoe) Mg. Coy.	
AP/104	,,	Redcap Plans (30-39) accompanying report by Broadhurst 1953	Broken Hill South Ltd.	
1/22	,,	Redcap Plan diamond drill holes	New Chillagoe Rlwy. & Mines Ltd.	50 ft.
	,,	Lady Jane 210 ft., 150 ft., 120 ft. levels, cross section	Mungana (Chillagoe) Mining Co. Ltd.	30 ft.
	,,	Hensey 67 Plan (1904)	,, ,, ,, ,, ,,	30 ft.
	,,	Morrison Section (longit.), showing assay values (1904)	New Chillagoe Rlwy. & Mines Ltd.	30 ft.
	,,	Ti-Tree D.D. Bores plan	,, ,, ,, ,, ,,	50 ft.
	,,	,, ,, ,, section	,, ,, ,, ,, ,,	30 ft.
	,,	Wilson Lease D.D. Hole plan	Chillagoe State Smelters & Mines	40 ft.
	,,	,, ,, No. 1 D.D. Section	,, ,, ,, ,,	20 ft.
	,,	,, ,, No. 2 D.D. Section	,, ,, ,, ,,	8 ft.
1/22	Chillagoe	,, ,, No. 3 D.D. Section	Chillagoe State Smelters & Mines	8 ft.
	,,	,, ,, New Shaft Cross Section	,, ,, ,, ,,	8 ft.
1/28	,,	Mt. Wandoo Gold Mine, plan of workings		20 ft.
1/30	,,	Morrison Mine Cross Section, showing 3 schemes for testing lode deeper	Chillagoe Railway & Mines Ltd.	30 ft.
1/33	Mungana	I.G.E.S. Electrical Sec. Mungana Equipotential Reconnaissance	I.G.E.S.	100 ft.
1/38	Chillagoe	Queenslander 14 M section	New Chillagoe Rlwy. & Mines Ltd.	30 ft.
		,, ,, summary ore reserves (1908)	,, ,, ,, ,, ,,	

G.S.Q. Ref. No.	Area	Subject	Authority — Author or Owner	Scale (to 1″)
AP/121 1/3	Mungana Herberton & Chillagoe	Plans, Geological Mapping, Red Dome area & Sketch Map of Herberton and Chillagoe G & M. Field carrying geological information	Chillagoe Prospecting Syndicate	110 ft.
	Wolfram	Wolfram mining map	Geological Survey Office	6 mile 5 ch.
AP/93		Redcap Area, including Queenslander, Morrison, Penzance, McIlwraith & Nellie plans & sections	Broken Hill South Ltd.	
AP/94	,,	Redcap area, plans and sections	,, ,, ,, ,,	
AP/95	,,	Ruddygore, plans and sections	,, ,, ,, ,,	
AP/96	,,	Girofla and Lady Jane, plans and sections	,, ,, ,, ,,	
AP/99	,,	Eastern portion of Mungana Lode, including Griffith, Calumet and Magazine. Face plans and sections.	,, ,, ,, ,,	
AP/108	,,	Mungana field, plans and sections 1-29	,, ,, ,, ,,	
AP/109	,,	Ruddygore, plans and sections	,, ,, ,, ,,	
AP/23	,,	Walsh R.	Chillagoe Oil Prospect	

MAPS, PLANS AND SECTIONS OF MINES ON THE ALMADEN, CHILLAGOE AND MUNGANA ONE-MILE SHEETS ON FILE AT THE GEOLOGICAL SURVEY OF QUEENSLAND OFFICE

Part 2: Plans by E. Broadhurst of the Mount Redcap area, accompanying final report to Broken Hill South Ltd, April 1948.

Q.G.S. Ref. No.	Subject
3/1	Regional Plan.
3/2	Outcrop and Boundary Map.
3/3	Surface Plan—Geological Interpretation.
3/4	Cross Section at 6,000 N.
3/5	Redcap Tunnel Level—early data.
3/6	Queenslander 117 ft. Level.
3/7	Queenslander 160 ft. Level.
3/8	Queenslander 200 ft. Level.
3/9	Queenslander Cross Section.
3/10	Queenslander Longitudinal Projection.
3/11	Morrison No. 1 Level.
3/12	Morrison No. 2 Level.
3/13	Morrison No. 3 Level.
3/14	Morrison Cross Section.
3/15	Morrison Longitudinal Projection.
3/16	Morrison Section showing assay values.
3/17	McIlwraith 60 ft. Level.
3/18	McIlwraith 80ft. Level.
3/19	McIlwraith 150 ft. Level.
3/20	McIlwraith 250 ft. Level.
3/21	McIlwraith and Penzance Cross Section; McIlwraith Longitudinal Projection.
3/22	Penzance Longitudinal Projection.
3/23	Nellie 70 ft. Level.
3/24	Nellie 95 ft. Level.
3/25	Nellie 145 ft. Level.
3/26	Nellie Cross Section.
3/27	Victoria 100 ft. Level.
	Plans prepared by M. L. Wade, April 1948 to August 1949, showing results of exploration during that period.
3/28	Redcap Tunnel Level—Assay Plan.
3/29	Redcap Longitudinal Section through Tunnel.
3/34	Redcap E-W Section 9210 N.
3/35	Redcap E-W Section 9010 N.
3/36	Redcap Assay Plan—Central Portion.
3/37	Redcap Assay Plan—Northern End.
3/38	Redcap Surface Plan.
3/39	Redcap Assay Plan—Southern End.
3/40	Redcap Assay Plan—Southern Extension.
3/42	Queenslander Cross Section across Main Shaft.
3/43	Queenslander E-W Section 7950 N.
3/44	Redcap Plans down No. 1 winze.
3/46	Redcap E-W Section No. 1 winze.

Q.G.S. Ref. No.	Subject
3/47	Redcap Plans down No. 1 winze.
3/48	Redcap N-S Section along west wall open cut.
3/49	Redcap E-W Section 9180 N.
3/50	Redcap Section through No. 1 Shaft and South Winze.
3/51	Redcap Tunnel Level—Geological Interpretation.
3/52	Redcap N-S Section No. 1 Winze.
3/54	Redcap E-W Section down No. 2 Shaft.
3/55	Redcap N-S Section along Eastern Lens.
3/56	Redcap E-W Section 8900 N, showing suggested d. d. hole Plans accompanying report by E. Broadhurst, Dec., 1949:
3/57	Redcap Geological Interpretation 1″ = 100′.
3/58	Redcap Geological Interpretation 1″ = 200′.
	Plans showing geophysical results, 1930 Survey, and plates accompanying geophysical report by Bureau of Mineral Resources, 1950:—
3/60	I.G.E.S. Equipotential Reconnaissance Survey, 1930.
3/61	Plate G84-1 Plan of Chillagoe-Mungana District, showing locations of areas surveyed.
3/62	Plate G84-2 Mungana Area: Geology, Geophysical Layout and axes of Electromagnetic Indications.
3/63	Plate G84-3 Mungana Area: Electromagnetic Profiles for Real Horizontal and Vertical Components.
3/64	Plate G84-4 Mungana Area: Magnetic Vertical Force Profiles.
3/65	Plate G84-5 Shannon-Zillmanton Area: Geology, Geophysical Layouts and Axes of Electromagnetic Indications.
3/66	Plate G84-6 Zillmanton Area: Electromagnetic Profiles for Real Horizontal and Vertical Components.
3/67	Plate G84-7 Zillmanton Area: Gravity Profiles and Plan showing Correlation between E. M. Axis and known ore.
3/68	Plate G84-8 Shannon Area: Electromagnetic Profiles for Real Horizontal and Vertical Components.
3/69	Plate G84-9 Shannon Area: Electromagnetic Profiles (Imaginary Components) and results of Resistivity Tests.
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3/72	Plate G84-12 Redcap Area: Electromagnetic Profiles for Real and Imaginary Horizontal and Vertical Components.
3/73	Plate G84-13 Redcap Area: Gravity Profiles and Contours.
3/74	Plate G84-14 Redcap Area: Results of Magnetic Survey and Resistivity Tests.
3/75	Plate G84-15 Queenslander Area: Electromagnetic Profiles for Real and Imaginary Horizontal and Vertical Components.
	Plans showing results of drilling 1950-1951:
3/76	Redcap-Queenslander Longitudinal Projection.
3/77	Redcap-Queensland Cross-sections 74OON-84OON.
3/78	Redcap-Queenslander Cross-sections 86ON-96OON.
	Plans accompanying notes by C. J. Sullivan, August, 1951:
3/79	Redcap-Queenslander Longitudinal section.
3/80	Redcap Section through No. 1 Shaft and South Winze.
3/81	Redcap Section through No. 1 and 3 Diamond Drill holes.

AUSTRALIA 1:63,360

CHILLAGOE
QUEENSLAND

1 MILE GEOLOGICAL SERIES SHEET 55 ZONE 7

FIRST EDITION 1964

Reference

CAINOZOIC	QUATERNARY	Qa	Alluvium and soil
		Czs	Granite sand and sheet flood deposits
PALAEOZOIC	UPPER PALAEOZOIC		Dykes: d = dolerite, q = quartz, qp = coarse quartz-feldspar porphyry, r = rhyolite
		Elizabeth Creek Granite — Pgz	Pink, leucocratic, biotite granite, granite porphyry, aplite
		Featherbed Volcanics — Pf	Massive, dark grey ignimbrites
		Pf	Acid, pale-weathered lavas and pyroclastics commonly flow-banded
		Almaden Granite — Pga	Grey, biotite-hornblende adamellite and granodiorite
		Almaden Granite? — Pga?	Biotite-hornblende quartz diorite and granodiorite
		Herbert River Granite — Pgh	Soft pink to grey, hornblende-biotite adamellite
		Doolan Creek Rhyodacite — Pd	Grey or greenish, red-weathered, porphyritic rhyodacite and dellenite
	L. CARBONIFEROUS -MIDDLE DEVONIAN	Hodgkinson Formation — D-Ch	Mississippian and Devonian greywacke, siltstone, shale, subordinate chert, conglomerate, limestone. Mono chert lenses
	(LOWER DEVONIAN?) -UPPER SILURIAN	Chillagoe Formation	S-Ch: Massive reef limestone; S-Ch: Limestone breccia or conglomerate; S-Ch: Chert; S-Ch: Quartz greywacke and siltstone
PRECAMBRIAN	ARCHAEAN?	Dargalong Metamorphics — Ad	Amphibolite, gneiss, mica schist, quartz schist

- Geological boundary
- Fault
- Where location of boundaries, folds, and faults is approximate, line is broken, where inferred, queried, where concealed, boundaries and folds are dotted, faults are shown by short dashes
- Strike and dip of strata
- Vertical strata
- Overturned strata
- Dip < 15°
- Horizontal strata (air-photo interpretation)
- Joint pattern
- Trend lines
- Strike and dip of platy flow
- Platy flow, vertical
- Direction of sedimentation
- Top of bed
- Gossan, replacement lode, skarn rock
- Fe — Magnetite - hematite rock
- Ga — Garnet
- Hot Spring
- W — Well
- Windpump
- Dam
- WH — Waterhole
- Cu — Minor mineral occurrence
- Mine, open cut or prospect
- Ag — Silver
- Au — Gold
- Bi — Bismuth
- Cu — Copper
- F — Fluorspar
- Pb — Lead
- Mo — Molybdenum
- W — Tungsten
- Sn — Tin
- Road
- Vehicle track
- Railway with station
- Landing ground
- Telegraph line
- "Chillagoe" — Homestead
- Dwelling
- Site of former village, now abandoned
- Treatment plant, smelter (deserted)

Compiled and published by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development, in conjunction with the Geological Survey of Queensland. Topographic base compiled by the Division of National Mapping, Department of National Development. Aerial photography by the Royal Australian Air Force, complete vertical coverage at 1:50,000 scale. Transverse Mercator Projection

Geology, 1958, by: F. de Keyser and M.B. Bayly (B.M.R.), K.W. Wolff (Q.G.S.)
Compiled, 1960, by: F. de Keyser and K.W. Wolff
Drawn by: Drafting Section, Department of Mines, Queensland

INDEX TO ADJOINING SHEETS
Showing Magnetic Declination

WALSH		MOSSMAN
	YORAS / MT MILLERAN / BIBOOHRA	
	MUNGANA / CH LLADOE / DIMBULAH	
	F SCHERTON / ALMADEN / HODGKINSON	
RED RIVER		ATHERTON

Annual Change 2°E

Scale
1 Mile to 1 Inch
1 0 1 2 3 4 5 MILES
1 0 1 2 3 4 5 KILOMETRES

GEOLOGICAL RELIABILITY DIAGRAM
A Detailed mapping
B Reconnaissance traverses and air photo interpretation
C Air photo interpretation only

DIAGRAMMATIC RELATIONSHIP OF ROCK UNITS
West — East
Chillagoe Formation: S-Ch, S-Ch
Featherbed Range: Pf, Pf
Almaden Granite: Pga, Pga
Herbert River Granite: Pgh
Doolan Creek Rhyodacite: Pd
Hodgkinson Formation: D-Ch, D-Ch
Unconformity

Sections
(Vertical exaggeration)
Scale 1/2 in = 1 mile

A — B
PAL MERVILLE FAULT
Quaker Creek
ALMADEN-CHILLAGOE ROAD
RAILWAY
Hobson
Five Chain Bend
Crooked Creek
Jamtin Creek
Punchpot Creek
FEATHERBED RANGE
WALSH RIVER
2400' 2100 1800 1500 1200 900

C — D
FEATHERBED RANGE
Four Mile
WOLFRAM CAMP ROAD
3000 2700 2400 2100 1800 1500 1200 900

Printed by Mercury Press, Hobart

Copies of this map may be obtained from the Bureau of Mineral Resources, Geology and Geophysics, Canberra, A.C.T., or the Geological Survey of Queensland, Brisbane

CHILLAGOE
SHEET 55 ZONE 7

AUSTRALIA 1:63,360

MUNGANA
QUEENSLAND

1 MILE GEOLOGICAL SERIES SHEET 54 ZONE 7

FIRST EDITION 1964

Reference

CAINOZOIC	QUATERNARY		Qa — Alluvium and soil
			Qes — Sand derived from Klw
MESOZOIC	LOWER CRETACEOUS	Wrotham Park Sandstone	Klw — Sandstone, conglomerate, some shale
PALAEOZOIC - MESOZOIC	(LOWER TRIASSIC?) - UPPER PERMIAN		Dyke or vein (Predominantly ar-photo interpretation) and: and=andesite, d=dolerite, q=quartz, qp=coarse quartz-feldspar porphyry, r=rhyolite
		Undifferentiated Granites	Pgu — Hornblende diorite, muscovite-biotite granite, coarse pink granite
		Elizabeth Creek Granite	Pgz — Pink biotite granite, microgranite-porphyry, fine-grained leuco-granite
		Featherbed Volcanics	Pf — Felsite, tuff, massive grey ignimbrite
		Almaden Granite	Pga — Grey, biotite-hornblende adamellite and granodiorite
		Almaden Granite?	Pgs — Biotite-hornblende granodiorite and hypersthene-augite-quartz diorite
		Herbert River Granite	Pgh — Pale-pink to grey, medium-grained biotite adamellite, with hornblende
		Nychum Volcanics	Pan — Grey ignimbrite and pyroclastics basal agglomerate; Agglomerate
		Doolan Creek Rhyodacite	Pd — Grey or greenish, porphyritic rhyodacite and dacite
	PERMIAN ?	Undifferentiated Volcanics	Pzur — Grey, pink or dark, porphyritic micro-adamellite
	LOWER DEVONIAN (UPPER SILURIAN ?)		S-Dn — Quartz greywacke, siltstone, with subordinate chert conglomerate, Main conglomeratic lenses, Main chert lenses
	(LOWER DEVONIAN ?) - UPPER SILURIAN	Chillagoe Formation	S-Dh — Massive reef limestone
			S-Dh — Limestone breccia or conglomerate
			S-Dh — Bedded chert
			S-Dh — Conglomerate
			S-Dn — Quartz greywacke, siltstone, sandstone; some mudstone
			S-Dh — Basic volcanics
			S-Dh — Quartz sandstone, quartz siltstone
PRECAMBRIAN	ARCHAEAN?	Dargalong Metamorphics	Gr — Muscovite granite, non-foliated
			Ag — Predominantly pegmatite and granitic gneiss
			Ad — Predominantly quartz-mica schist with quartzite
			As — Predominantly mica schist
			Ah — Amphibolite

- Geological boundary
- Syncline
- Fault

Where location of boundaries, folds, and faults is approximate, line is broken; where inferred, queried, where concealed, boundaries and folds are dotted, faults are shown by short dashes

- Strike and dip of strata
- Prevailing direction of dip of strata
- Vertical strata
- Overturned strata
- Prevailing dip of highly deformed strata
- Strike and dip of disturbed strata
- Strike of disturbed vertical strata
- Top of bedding
- Direction of sedimentation
- Trend lines
- Joint pattern
- Horizontal strata

(ar-photo interpretation)

- Strike and dip of metamorphic foliation and schistosity
- Vertical foliation and schistosity
- Generalized strike of vertical undulating foliation
- Direction and plunge of lineation
- Foliation with plunge of lineation
- Strike and dip of platy flow in igneous rocks
- Vertical platy flow
- Gossan, ferruginous lode
- Mine, open cut or prospect
- Alluvial workings
- Ag — Silver
- Au — Gold
- Cu — Copper
- F — Fluorspar
- La — Travertine
- Mi — Mica
- Mn — Manganese
- Pb — Lead
- R — Rutile
- Smelter (deserted or abandoned)
- Bore or well with windpump
- Spring
- Waterhole
- Road
- Vehicle track
- Railway (abandoned in 1961)
- Telegraph line
- Homestead
- Dwelling
- Yard
- Site of former mining town, now abandoned
- Trigonometrical station
- Height in feet, instrument levelled datum: mean sea level
- PO — Position doubtful

Compiled and published by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development, in conjunction with the Geological Survey of Queensland. Topographic base compiled by the Division of National Mapping, Department of National Development, Aerial photography by the Royal Australian Air Force; complete vertical coverage at 1:50,000 scale. Transverse Mercator Projection.

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Compiled, 1962, by F. de Keyser and K.W. Wolff
Drawn by: Drafting Section, Department of Mines, Queensland.

INDEX TO ADJOINING SHEETS
Showing Magnetic Declination

WALSH			MOSSMAN
	RADNOR	TOXAS	MT. MULLIGAN
	BLACKDOWN	MUNGANA	CH LLADDE
	RED RIVER	FISCHERTON	ALMADEN
RED RIVER			ATHERTON

Annual Change 2'E

Scale
1 Mile to 1 Inch
1 0 1 2 3 4 5 MILES
1 0 1 2 3 4 5 KILOMETRES

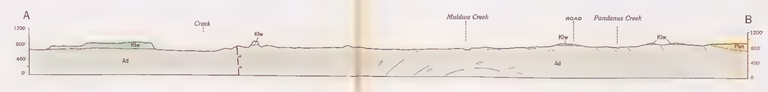
GEOLOGICAL RELIABILITY DIAGRAM

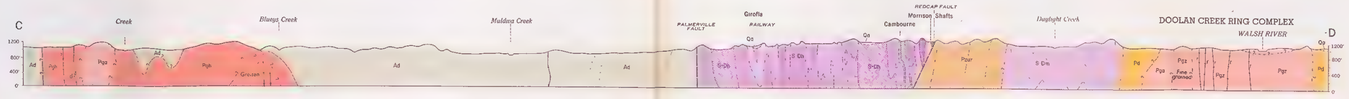
A — Detailed mapping
B1 — Detailed reconnaissance, numerous traverses
B2 — As photo interpretation and traverses

DIAGRAMMATIC RELATIONSHIP OF ROCK UNITS

Direction of sedimentation
Unconformity

Sections
Scale X = 2Y
(Floating diagrammatic)





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MUNGANA
SHEET 54 ZONE 7

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AUSTRALIA 1:63,360

ALMADEN
QUEENSLAND

1 MILE GEOLOGICAL SERIES SHEET 60 ZONE 7

FIRST EDITION 1964

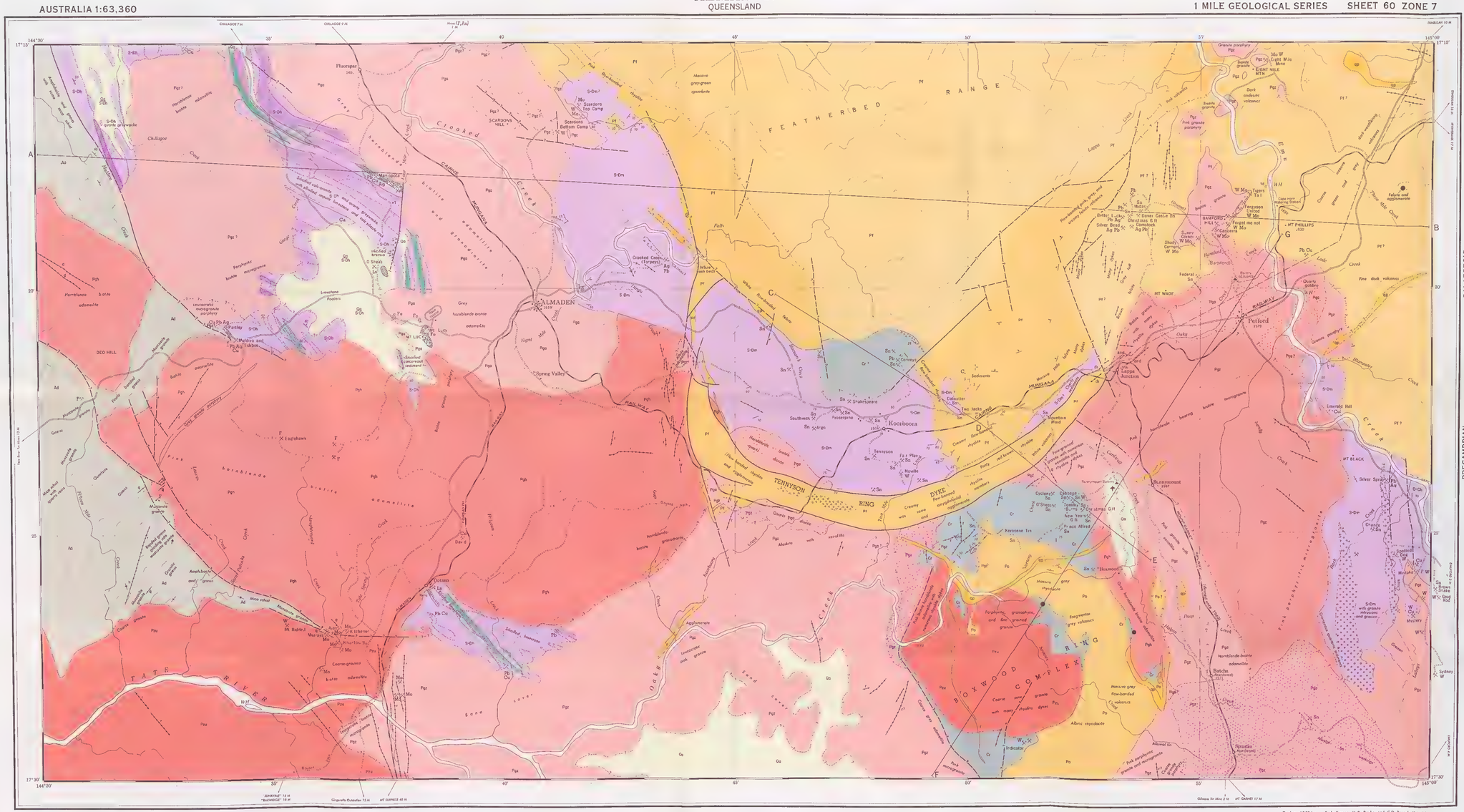
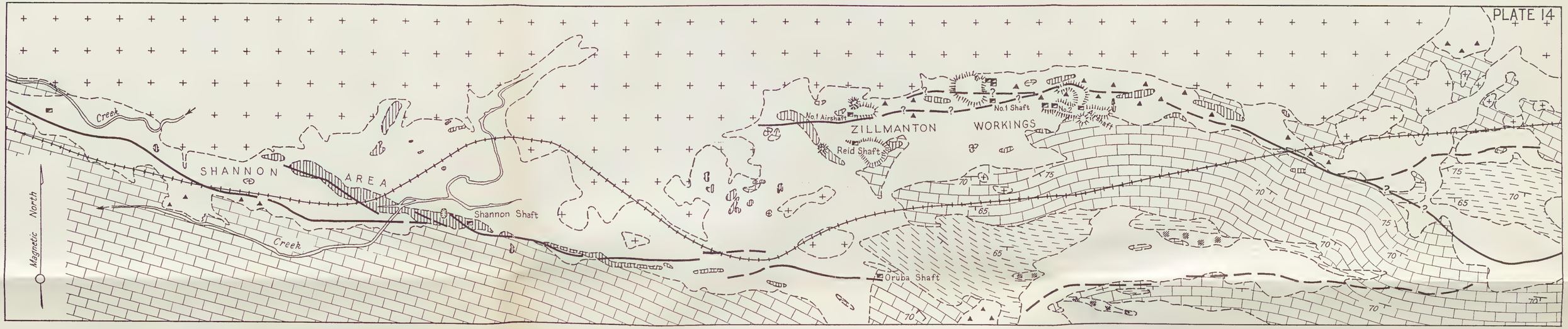

FEATHERBED RANGE
BOXWOOD COMPLEX RING
DYKE
TENNYSON RING
ALMADEN
Koonboora
Petford
Chillagoe
Gorge Creek
Manoopota
Four Mile Creek
Crooked Creek
Oaky Creek
Tate River
Mungana
Mt Phillips
Bamford Hill
Dotsam
Fluorspar
Seasons Bottom Camp
Scarsons Top Camp
Sonne Valley
Eaglehawk
Deco Hill
Mt Lucy
Mt Wade
Mt Black
Emerald Hill
Sunnymount
Batchelor
Federal Sn
Silver Bread Ag Pb
Bitter Lass Pb Ag
Forget me not W Mo
Tigers Ta
Eight Mile Mine
Ferguson United W Mo
Quarry (gabbro) Pg
Fine dark volcanics
Course grey and green volcanics
Massive grey flow-banded volcanics
Albitic rhyodacite
Massive grey-green quartz-feldspar porphyry
Pink granite porphyry
Dark andesitic volcanics
Pink biotite granite
Pink biotite granite porphyry
Pink porphyritic biotite granite and microgranite
Massive grey-green quartz-feldspar porphyry
Pink porphyritic granite and microgranite
Coarse-grained biotite adamellite
Pink biotite granite
Pink hornblende biotite adamellite
Pink biotite adamellite
Pink hornblende biotite adamellite
Pink biotite granodiorite
Pink hornblende biotite granodiorite
Pink hornblende biotite monzogranite porphyry
Grey hornblende biotite granodiorite
Grey hornblende biotite adamellite
Pink hornblende biotite adamellite
Pink hornblende biotite monzogranite
Pink hornblende biotite granodiorite
Pink hornblende biotite adamellite
Pink hornblende biotite granodiorite
Pink hornblende biotite adamellite
Pink hornblende biotite granodiorite
Pink hornblende biotite adamellite
Pink biotite granodiorite
Pink biotite adamellite
Pink biotite granodiorite
Pink biotite adamellite
Pink biotite granodiorite
Pink

PLATE 14



SHANNON - ZILLMANTON AREA
ATHERTON, QUEENSLAND

Showing geology and axes of electromagnetic anomaly
(After W.J.Langron, 1957 and C.D.Branch, 1959)

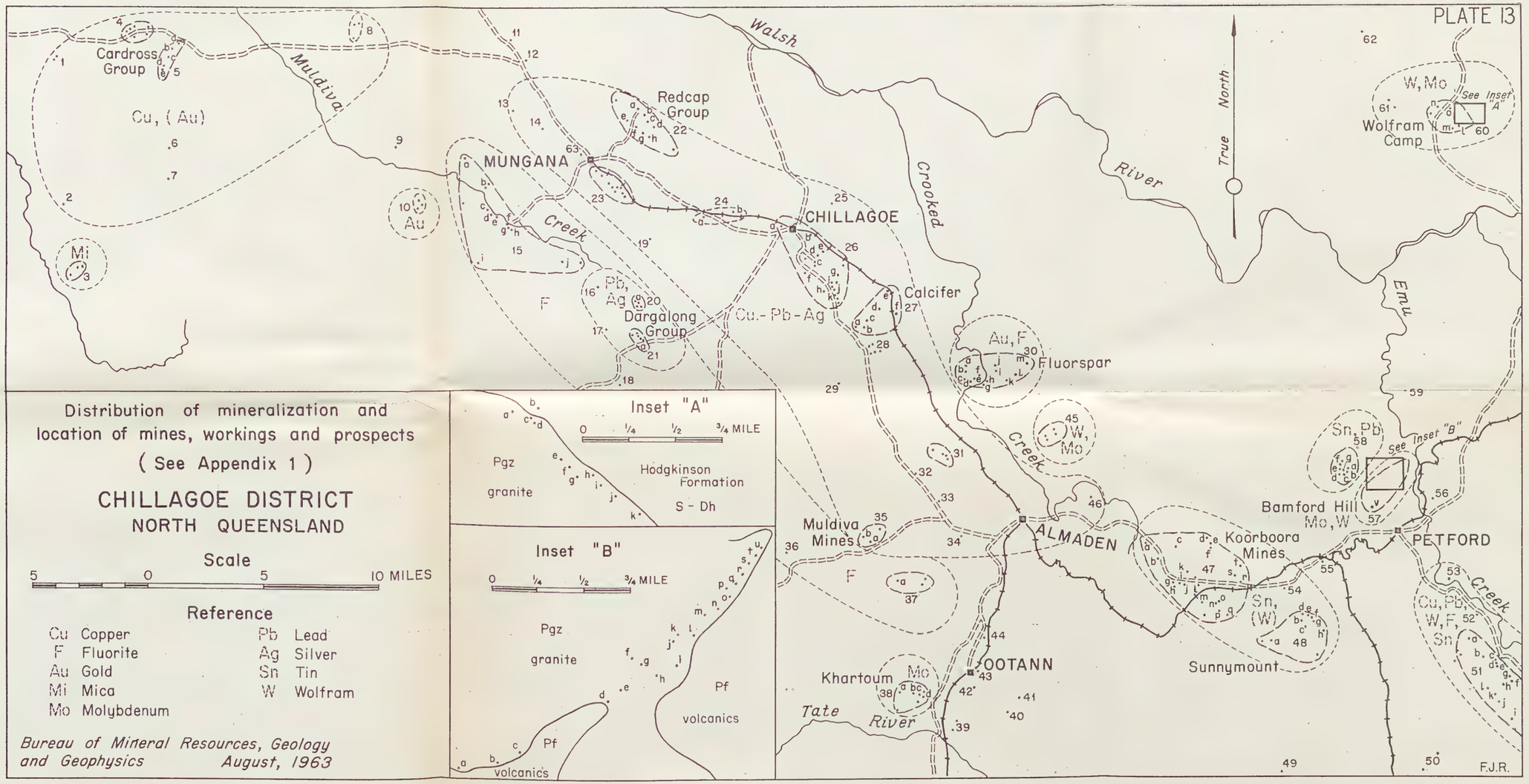
Scale
500 0 500 1000 1500 Feet

- *Alluvium, soil*
- Almaden Granite *Hornblende-biotite granodiorite*
- *Marble*
- *Calc-silicate rock*
- *Chert or silicified quartz siltstone with disseminated pyrite*
- *Lode material : siliceous haematite*

Reference

- *Haematite rubble*
- *Axis of electromagnetic anomaly, line broken where medium or weak*
- *Geological boundary*
- *Strike and dip of bedding*
- *Vertical bedding*
- *Prevailing strike and dip of cleavage*
- *Shaft*
- *Open cut*
- *Dump*
- *Railway*
- *Bridge*

PLATE 13



Distribution of mineralization and location of mines, workings and prospects

(See Appendix 1)

CHILLAGOE DISTRICT
NORTH QUEENSLAND

Scale

5 0 5 10 MILES

Reference

Cu	Copper	Pb	Lead
F	Fluorite	Ag	Silver
Au	Gold	Sn	Tin
Mi	Mica	W	Wolfram
Mo	Molybdenum		

Bureau of Mineral Resources, Geology and Geophysics *August, 1963*

F.J.R.

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QUEENSLAND
DEPARTMENT OF MINES

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GEOLOGICAL SURVEY OF QUEENSLAND
(A. K. Denmead, M.Sc., Chief Government Geologist)

PUBLICATION No. 318

STRATIGRAPHY OF THE ROMA–WALLUMBILLA AREA

By R. W. DAY, B.Sc. (Hons.), Geologist

BRISBANE
By Authority: S. G. REID, Government Printer
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FOREWORD

Mr. Day's paper deals with a region of special significance in the history of Queensland stratigraphy. The first Mesozoic fossils recorded in Australia were found at Wallumbilla; the earliest work on the intake beds of the Great Artesian Basin was centred about the town of Roma; and the search for oil in Queensland was concentrated for fifty years in the Roma-Wallumbilla area.

Many geologists, some of world renown, have studied the local geology; each has interpreted the stratigraphy in his own way and no two have been in complete accord. It is not to be wondered at, then, that the nomenclature of the sedimentary formations over the years has become confused.

By careful mapping with the aid of air photos, supplemented by a critical study of bore records and detailed sedimentology studies, Mr. Day has produced a new map and a new interpretation.

Inevitably, since the region is one of exceptional economic interest, there will be further and more refined studies which will necessitate modifications of Mr. Day's interpretations.

The value of the paper lies partly in the detailed review of all previous investigations, but chiefly in the new definitions of all the stratigraphic units in accordance with the Australian Code of Stratigraphic Nomenclature backed by detailed field and laboratory studies.

A. K. DENMEAD,
Chief Government Geologist.

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STRATIGRAPHY OF THE ROMA-WALLUMBILLA AREA

By R. W. Day, B.Sc., Geologist

ABSTRACT

Jurassic and Lower Cretaceous sediments overlying the Injune Creek Beds in this part of the Surat Sub-basin are divided into four formations:—from the base, Gubberamunda Sandstone (50–200 ft.), Orallo Formation (350–450 ft.), Blythesdale Formation (500–550 ft.) and Roma Formation (200 ft.). The sequence is apparently conformable. The names of the three older units are selections from informal ones based on priority, and the units are re-interpreted in terms of their original usage, and type areas have been designated. Wherever possible, details of sedimentary sequences within each unit are given, and correlations are made with sections penetrated in oil wells. In the Blythesdale Formation four members are recognized:—from the base, Mooga Sandstone (150–200 ft.), Kingull (200 ft.), Nullawurt Sandstone (50 ft.) and Minmi (50-70 ft.). The youngest is marine, the remainder freshwater, as are the Orallo Formation and the Gubberamunda Sandstone.

Preliminary determinations of the flora and the freshwater and marine faunas are tabulated. The previously accepted premise that the rib development in *Maccoyella barklyi* (Moore), attributed to mutations, was of stratigraphic significance, is shown to be invalid.

Unfossiliferous Cainozoic sediments are widespread, but often of limited outcrop area and thickness. They comprise lateritised Tertiary sandstones, possibly equivalent to the Telgazli Formation of the Surat area; Tertiary sands and gravels, in part underlying basalt; mottled sand of probable Upper Tertiary age; residual sands and gravels varying in age; and Quaternary sediments of the present drainage system.

The area has figured prominently in the search for oil and natural gas, and wells are indicated on the map and section.

INTRODUCTION

The region studied covers about 1,300 square miles between lat. 26°15′S. and lat. 26°40′S., and between long. 148°30′E. and long. 149°15′E.; that is, a block extending from Wallumbilla in the east to Bindango Siding in the west, with a northern limit 24 miles north of Roma and a southern one 4 miles south of Roma. It occupies the central western portion of the area of the Roma 4-mile military map. Complete aerial photographic cover is provided by the Roma 1:83,000 (May, 1962) photography, and the Roma, Yingerbay, Muggleton, and Yuleba 30 chain series, all flown by Adastra.

Work in this area was initiated in 1959 as a post-graduate research project with the Department of Geology and Mineralogy in the University of Queensland, and an honours thesis was submitted in 1960. Subsequent to joining the staff of the Geological Survey of Queensland in 1961, work was continued in the area, and this has enabled enlargement of the scope of the original mapping project as well as its revision for this publication.

Grateful acknowledgement is made of the assistance to the initial project rendered by members of the Department of Geology and Mineralogy, notably to Professor D. Hill and Dr. W. G. H. Maxwell. Thanks are also due to Mr. J. T. Woods, formerly Supervising Geologist, Geological Survey of Queensland for helpful discussion.

The mapping is based on photo-interpretation controlled by numerous ground traverses. The base map was compiled by the Drafting Section, Department of Mines, from 1:83,000 (May, 1962) Adastra photography, with slotted template assembly supplied by courtesy of Department of National Mapping, Canberra. Map references in the text are to the grid of the Roma 4-mile military map.

The formations mapped have been compared with sequences penetrated in the oil wells of the area and, wherever possible, correlations made. Useful information has been obtained from the examination of old well logs and cores housed in the Geological Survey of Queensland, but the subsurface study has been far from exhaustive. Oil wells are indicated on the map and in the text as standard abbreviations; full names are given by Geological Survey of Queensland (1960).

Representative sediments have been examined in thin section and their percentage composition estimated visually with the aid of the chart of Folk (1951). Sedimentary nomenclature is that of Pettijohn (1957). The incoherent nature of the sediments enabled textural studies by mechanical analysis.

Large collections of fossils were made, and these, together with extensive collections housed in the Geological Survey of Queensland, have been examined as a preliminary to determining their usefulness as index fossils for stratigraphic subdivisions of Lower Cretaceous sediments of the Great Artesian Basin. The identifications are tabulated in stratigraphic order (Tables 3 and 4). All fossil localities mentioned in the tables are shown on the map.

Within the area under review Cainozoic, Cretaceous, and Jurassic strata outcrop (Table 1). Several stratigraphic units have been named from this area and although the names have been widely applied to sediments throughout the Great Artesian Basin, only one—the Roma Formation—has been formally defined, while details of the lithologies and sedimentary sequences of these units are lacking. In particular the subsequent wide usage and loose application of the Blythesdale Group of Whitehouse (1955) makes provision of a standard of reference imperative, and the present stratigraphic revision was undertaken with this end in view.

TABLE 1

EXPOSED ROCKS OF THE ROMA–WALLUMBILLA AREA

Cainozoic	Quaternary		Alluvium 0–50 ft. Residual sand and gravel	
	Tertiary		Mottled sand 6 ft.+ Basalt flows and intrusives 150 ft. + Lateritised sandstone 150 ft. +	
Mesozoic	Lower Cretaceous	Aptian	Roma Formation 200 ft. Minmi Member 50–70 ft.	Blythesdale Formation 500–550 ft.
		Neocomian	Nullawurt Sandstone Member 50 ft. Kingull Member 200 ft. Mooga Sandstone Member 150–200 ft.	
	Jurassic	Upper	Orallo Formation 350–450 ft. Gubberamunda Sandstone 50–200 ft.	
			Injune Creek Beds	

PREVIOUS WORK

Mention was made of the area quite early in the geological literature, when Clarke (1862) announced a find of Mesozoic marine fossils at Wallumbilla. This was apparently the first authentic record of Mesozoic fossils from eastern Australia. Clarke (1867) later provided notes on the geology, and Moore (1870) described and figured the Wallumbilla fossils. Coxen (1864) also recorded geological observations. The first geological survey of any consequence was that by Jack and Maitland in 1894, as part of the mapping of intake areas of the Great Artesian Basin. As a result of this work a new unit, the Blythesdale Braystone was recognized (Jack 1895a, b). In 1913 a second artesian water survey was made by Saint-Smith, whose misinterpretation of Jack's unit (Saint-Smith, 1914) was responsible for much of the subsequent confusion in the stratigraphic names applied to the sediments of the area. The decade between 1920 and 1930 saw contributions to the stratigraphy by Jensen (1926b) and Ball (1927a, b). These authors recognized several units, but gave them informal names. An important development was the subdivision by Reeves (1947) of the freshwater sediments into four units: "Gubberamunda Sandstone", "Fossil Wood Stage or Series", "Mooga Sandstone", and "Transition Stage or Series". These units, together with the marine sandstones immediately underlying the Roma Formation, comprise the Blythesdale Group of Whitehouse (1955). In the same paper Whitehouse formally named the "Roma Series" (Whitehouse, 1926a) the Roma Formation. The most recent contribution is Jensen's (1960) revision of his earlier work.

Since 1900 when petroliferous gas was discovered at Roma, this area has been the focus of considerable attention by geologists, and there is a large volume of literature, published and unpublished, concerning the siting of oil wells and the potential of the area as an oil and gas field. A detailed summary of the earlier work is given by Cameron (1915). Later summaries are provided by Reeves (1947) and by Geological Survey of Queensland (1960). Some results of the current exploration programme are given by Traves and Thralls (1960), while an assessment of the prospects of the area in terms of reservoir potential is provided by Traves (1962).

PHYSIOGRAPHY AND VEGETATION

The area is one of mature topography and little relief. The general elevation of the country around Roma is about 1,000 ft. above sea level, rising to about 1,300 ft. at the Great Dividing Range, some 25 miles to the north. This range is such only in name here, for it is an inconspicuous stream divide.

By far the most prominent topographic feature is the Grafton Range, a south-westerly trending spur of the Great Divide, which divides the area into two approximately equal portions and rises to about 1,600 ft. Much of it is flat-topped, due to basalt capping, as is its now separated southern extension, Mt. Bassett. The only other features to approach this height are laterite-capped buttes in the vicinity of Cox's Hill, 12 miles north of Wallumbilla.

Except for Barton and Sugarloaf Creeks on the northern side of the Great Divide, which contribute to the Dawson-Fitzroy system, drainage is southwards to the Balonne River, which ultimately empties into the Darling. There are three major watercourses which join further to the south. They are from west to east, Bungeworgorai, Bungil, and Blyth Creeks. Other important, though smaller creeks are the Clerk, Mooga

Mooga, Warooby, Sleepy, Pickanjinnie, and Wallumbilla. Most changes of stream course mark points of outcrop of resistant rock, but there are notable exceptions in the minor creeks. The curved south-easterly course of Wallumbilla Creek south of Wallumbilla may have some structural control, because the outcrop of a *Purisiphonia* horizon, within the Roma Formation, follows the trend of the creek and extends further south than the topography and regional dip would suggest.

Several of the formations have distinctive topographic expression. This is especially so in the case of the basal sediments of the Blythesdale Formation (Mooga Sandstone Member), which form a prominent escarpment adjacent to Bungeworgorai and Bungil Creeks, and buttes and flat-topped ridges elsewhere. The laterite-capped buttes of Tertiary sediments north of Wallumbilla present a similar appearance, and are difficult to differentiate from the Blythesdale Formation by photo-interpretation; even in the field, distinction between the two is difficult in some places. A less broken, more undulating terrain characterizes the Orallo Formation. In adjacent outcrop areas, the mature rolling topography of the Roma Formation is in contrast to the steep gullying and more youthful appearance of the stratigraphically underlying marine part of the Blythesdale Formation. Ball (1927a, p.94) commented on this and suggested the difference was due to "recent crustal elevatory movements". However, it is apparently due only to differential erosion, the predominantly sandstone sequence of the Blythesdale Formation being more resistant than the shales of the Roma Formation.

The vegetation associated with the soils developed on the various formations is often quite distinctive, but, although broad generalisations are possible, exceptions are so numerous that caution in their application is necessary. A particular case is the distribution of brigalow (*Acacia harpophylla*). Outcrops of the Injune Creek Beds invariably carry thick stands of brigalow, but these are also common on the Kingull Member, Tertiary basalts, lateritised Tertiary sediments, and Quaternary residual sediments. On the other hand, brigalow stands on sediments of Blythesdale Formation are sporadic in their distribution. Generally, the areas with brigalow are well drained

View from Red Hill looking north-east. Grafton Range left background; Mt. Bassett right background.

View from the Roma-Orallo road at m.r. 155704 looking south-east, showing the typical surface appearance of the Roma Formation.

and overlie calcareous rocks. The distribution of forests of cypress pine (*Callitris robusta*) provides another example. These are extensively developed on the Gubberamunda Sandstone, but they also occur wherever there are tracts of loose sand, for example, on sands of the Orallo and the Blythesdale Formations as well as on high-level sandy alluvium.

Notwithstanding these limitations local changes in vegetation have proved extremely useful in delimiting the geological formations. This is particularly so in the mapping of the boundary between Gubberamunda Sandstone and Injune Creek Beds, and in distinguishing those areas of Roma Formation with a veneer of Quaternary residual sands and gravels from those without. Previously, Jensen (1926b) recognised the value of vegetation changes in geological mapping here.

MESOZOIC STRATIGRAPHY

Injune Creek Beds

Following the suggestion of Laing (1960) the name "Injune Creek Beds" of Jensen (1921) is adopted for this Formation. The unit was previously called "Lower or Calcareous Walloon" by Jensen (1926b), "Lower Walloon Coal Measures" by Reeves (1947), and "Walloon Coal Measures" by Whitehouse (1955). Since the Formation only outcrops in the extreme north-eastern corner of the area mapped, no comprehensive study was made of it. The palaeobotanical determinations listed by Willcox (1926) and Whitehouse (1955) indicate a probable Jurassic age for the unit—a conclusion previously reached by Jensen (1926b), Reeves (1947), and Whitehouse (1955). It has been customary to regard the Formation as an equivalent of the Walloon Coal Measures of the Moreton district.

Normally the thick growth of brigalow and belah associated with the clay soils developed on this Formation presents a considerable contrast to the cypress pine forest associated with the overlying Gubberamunda Sandstone. However, in the north-eastern corner of the map area the photo-interpretation and delimitation of the Injune Creek Beds are complicated by sheets of sand shed from the topographically more elevated Gubbermunda Sandstone, Orallo Formation, and Tertiary lateritised sandstones, which form the Great Divide here.

The outcropping sediments are fine-grained calcareous protoquartzites with thin bedding, and interbedded micaceous silty shales and siltstones. These closely resemble the fine-grained sediments of the Orallo Formation which outcrop in the Hunterton-Orallo area.

Gubberamunda Sandstone

This name was first used by Reeves (1947) and, although he did not designate a type area or section, his map and stratigraphic table leave no doubt as to the area of outcrop or place in the sequence of the unit so named. The type area is here designated as that part of the Parish of Gubberamunda near Bungil Creek, traversed by the main Roma-Injune road between 20 and 24 miles from Roma; that is, between m.r. 150737 and m.r. 153731.

The area along the Great Divide shown on the map of Jack and Maitland (1895) as "Desert Sandstone" includes some remnants of Tertiary sediments near the headwaters of Blyth Creek, but, in the main, approximates to the outcrop of the Gubberamunda Sandstone. Whitehouse (1955) regarded this unit as the basal Formation of the Blythesdale Group. The "Lower Silicified Wood Sandstone" of Jensen (1960) is equivalent to the Gubberamunda Sandstone.

There is considerable variation in the width of outcrop of the Formation. In the type locality, in the Blyth Creek headwaters, and north of Hunterton, it is between 4 and 6 miles, but on the Roma-Durham Downs road and on the Wallumbilla-Taroom road it narrows to about 0·5 mile. As the sediments are very friable, exposure is generally poor, and much of the area has a cover of loose, reddish sand. The contrast between the cypress vegetation developed on the outcrop of the Gubberamunda Sandstone and the brigalow stands associated with the underlying Injune Creek Beds is, as has already been noted, very marked. On the other hand, the vegetation associated with the sands of the overlying Orallo Formation is, in many cases, very similar to that associated with the Gubberamunda Sandstone.

Thickness and Lithology

Reeves estimated the thickness of the Gubberamunda Sandstone as 200 ft. and described it as a "medium-grained water bearing sandstone." Jensen (1960) gave the lithological characters of his "Lower Silicified Wood Sandstone" as "medium-grained siliceous sandstones" and estimated its thickness at 300 ft.

The variation in outcrop width seems to indicate variation in thickness, as dips are low (1° or less) and topography has only a minor influence. In the type area along Bungil Creek, the thickness is about 200 ft., but further east, on the Roma-Durham Downs road, it is apparently only about 50 ft. The unit then seems to thicken in the Blyth Creek headwaters, thinning again to about 50 ft. where it is crossed by the Wallumbilla-Taroom road.

The outcropping sediments are medium- and coarse-grained, virtually uncemented quartz sandstones, the medium grain size predominating. An examination

Outcrop of cross bedded Gubberamunda Sandstone in a tributary of Mooga Mooga Creek at m.r. 165734. Cross beds dip north-east.

of cores from A.A.O. No. 1 (Roma) well and cuttings from A.A.O. No. 5 (Hospital Hill) well has revealed that the Formation is represented in the former in the intervals 1,304-1,324 ft. (core 21) and 1,364-1,384 ft. (Core 22) and in the latter from 1,115 to 1,325 ft. In other wells drilled on Hospital Hill the Formation is represented by the prominent aquifer logged at depths between 1,200-1,400 ft. This compares closely with the interpretation of Reeves (1947, fig. 12). The subsurface information is sometimes difficult to interpret, for while there is an abrupt lithological change from shale to sand at the lower boundary of the Formation, the change at the upper one is rarely so pronounced, and many of the more argillaceous, feldspathic, and lithic sandstones of the Orallo Formation apparently have been logged as Gubberamunda Sandstone. This probably accounts for the thicknesses of 470 ft. and 502 ft. in A.A.O. Nos. 4 and 5 (Hospital Hill) wells respectively, as reported by Derrington and Hammett (1960). In A.A.O. Nos. 2 and 3 (Roma) wells the base of the Formation probably occurs at 1,100 ft., the depth reported by Mott (1960) as the base of the Blythesdale Group. These wells were sited several miles to the north, that is, up dip from those on Hospital Hill. From the writer's interpretation of the log of A.R.O. No. 10 (Orallo) well, which was sited only a few miles south of the outcrop of the Gubberamunda Sandstone, the unit is probably represented by the strata in the interval 350-517 ft., recorded as soft, grey and white, medium- and fine-grained sandstone. An inspection of the logs of the Blythdale wells has shown that the Formation is not so clearly defined here, but in A.R.O. No. 4 well it may be represented by the strata logged as sandy shale in the interval 1,105-1,311 ft. The garnetiferous horizons reported in A.A.O. Nos. 2 and 3 (Roma) (Mott, 1960), in A.A.O. Nos. 4 and 5 (Hospital Hill) (Derrington and Hammett, 1960), and in A.R.O. No. 11 (Blythdale) (Geological Survey of Queensland, 1960) are all apparently in the Gubberamunda Sandstone.

In thin section the rocks are seen to be orthoquartzites, with 25-40 per cent. of the quartz showing strain extinction. All but the larger grains are rather angular and elongate, with their long axes parallel to the bedding. Small quantities of perthite, microcline, and plagioclase may be present, and occasionally a few dark lithic fragments. The proportion of feldspar and lithic fragments is higher (10-12 per cent.) in the sediments exposed near the Wallumbilla-Taroom road at the top of the Formation (m.r. 209734 and m.r. 209736). In this respect they resemble the immediately overlying sediments of the Orallo Formation, which are, however, still less quartzose. Small amounts of ferruginous and chalcedonic cements may be present, but calcareous cement is absent.

Mechanical analyses of several samples show that these sandstones are medium- to coarse-grained, well-sorted, with sorting coefficients (So.) 1·25-1·52, and are virtually free of matrix.

Environment of Deposition

A notable feature of the Gubberamunda Sandstone is its cross-bedding. Often there are sets of cross-beds up to 5 ft. thick, with foreset beds so long and persistent that they could be mistaken for true bedding-planes. Cross-beds in exposures in Bungil Creek at m.r. 150735, near the Roma-Injune road at m.r. 150737, and in Appletree Creek at m.r. 195726 indicate south-westerly palaeocurrents. On a tributary of Mooga Mooga Creek at m.r. 165734, m.r. 165735, and m.r. 166736, the cross beds indicate south-easterly palaeocurrents; and in Blyth Creek at m.r. 194726, near Coxon Creek at m.r. 195724, and near the Wallumbilla-Taroom road at m.r. 209734, the palaeocurrents indicated are from the west. These are in distinct contrast to the north-westerly to north-easterly palaeocurrents which deposited the sandstones of the Orallo Formation. This difference in source is reflected in the mineralogy; for example, on the Wallumbilla-Taroom road near m.r. 209734 lithic and feldspathic subgreywackes of the Orallo Formation, with cross-bedding indicating deposition from the north-east, overlie protoquartzites of the Gubberamunda Sandstone, with cross-bedding indicating deposition from the west. It is not yet possible to suggest a location for the elevated westerly or south-westerly source of these sands.

The large scale cross-bedding, good sorting, and comparatively coarse grain size suggest deposition in a high energy, shallow-water, possibly fluviatile environment. In such an environment the variations in the thickness of the unit could be explained by irregularities in the depositional surface. Run-off was apparently unrestricted, as calcareous cements are absent. That the sediments are not of aeolian origin is evident from the the occurrence of more or less isolated pebbles, pebbly beds, and fragmentary fossil wood. The high percentage of quartz, much of it metamorphic, suggests a provenance of pre-existing quartzose sandstones.

Age and Stratigraphic Relationships

It is suggested that the Gubberamunda Sandstone was deposited in a fluviatile phase, following the essentially lucustrine conditions operative during the deposition of the Injune Creek Beds and that its variation in thickness may be due to an irregular depositional surface, though no actual disconformity can be established. In this connection the report by Geological Survey of Queensland (1960) of oxidised shales at 1,105 ft. in A.A.O. No. 3 (Roma) well may be significant, as the Injune Creek-Gubberamunda junction probably occurs at this depth. The relationship with the overlying Orallo Formation seems to be conformable. In the headwaters of Appletree and Yuleba Creeks on the Great Dividing Range the Gubberamunda Sandstone is unconformably overlain by Tertairy lateritised sandstones.

As diagnostic fossils have yet to be found in the Gubberamunda Sandstone its age is uncertain. Reeves (1947) included it in the Jurassic, as did Whitehouse (1955). The Roma Formation, which lies about 1,000 ft. stratigraphically above the Gubberamunda Sandstone, contains a marine fauna of Aptian age, so an Upper Jurassic age for the latter seems likely.

Orallo Formation

This replaces the name "Orallo Coal Measures" of Jensen (1960), the term coal measures being inappropriate. It is used here as a formal name for the "Fossil Wood Stage or Series" of Reeves (1947), later called the "Fossil Wood Beds" by Whitehouse (1955), who included the unit in his Blythesdale Group. It immediately underlies the Blythesdale Formation.

The "Orallo Coal Measures" of Jensen (1926b) included some of these sediments and apparently Injune Creek Beds as well, but the manner in which the name was proposed and used makes its interpretation virtually impossible. The name was only informally mentioned in the discussion of the "Middle Walloon" (p. 61), and as a heading in the section entitled "Cornwall-Alcurah Coals (Orallo Measures)" (p. 69). No type area was designated, and the unit was not shown on the map, although it did appear on the cross section (p. 26, fig. 3) as an upper division of the "Middle Walloon." The "Fossil Wood Horizon" or "Solitary Creek belt" of Jensen (1926b) is a part of the Orallo Formation.

In the revised work of Jensen (1960) the "Orallo Coal Measures" are shown on the sketch map and in the stratigraphic table as the carbonaceous shale and sandstone sequence, lying between the "Upper . . ." and "Lower Silicified Wood Stages." As these two units are approximately equivalent to the "Mooga Sandstone" and the "Gubberamunda Sandstone" respectively, of Reeves (1947), the "Orallo Coal Measures" can be interpreted as the approximate equivalent of the "Fossil Wood Stage" of Reeves (1947).

The type area is here designated as the area near Bungeworgorai Creek traversed by the road from Roma to Injune via Orallo, from 0·25 mile north of where this road crosses Spring Creek, about 0·5 mile north-west of Hunterton, south as far as the bend of Bungeworgorai Creek skirted by this road 20 miles from Roma; that is, between m.r. 127738 and m.r. 139723. The rail siding and village of Orallo (m.r.

132734) lie within the type area and give their name to the Formation. No satisfactory type section can be measured. About forty per cent. of the total thickness is exposed in the type area.

The outcrop is dependent on topography. In the lower lying country adjacent to Bungeworgorai, Bungil, and Blyth Creeks, the outcrop belt is 4 to 7 miles wide; at the northern extremity of the Grafton Range, where the Formation is largely covered by the Mooga Sandstone Member of the Blythesdale Formation, it narrows to 1·5 miles. The vegetation associated with the Formation is characteristically open eucalypt forest, with box and silver-leaf ironbark predominating, but stands of cypress pine are common on the sandier parts.

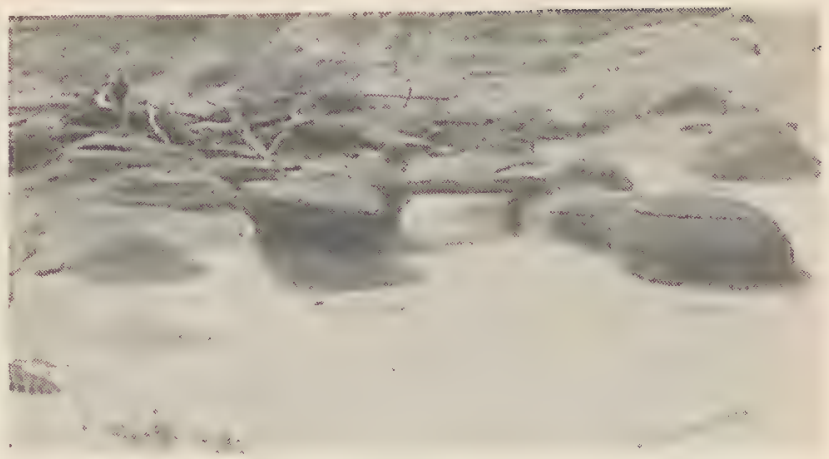
Thickness and Lithology

Reeves (1947) estimated the unit's thickness at 200-300 ft. and described its lithologies as "sandy clay shale, fine-grained arkosic sandstone, with lenses of coal and fossil wood." Jensen (1960) suggested a thickness of 700 ft. The present estimated thickness of 350-450 ft. obtained by considering a width of outcrop of 4 to 5 miles and a regional dip of 1° south, is in agreement with the thicknesses penetrated in oil wells of the area.

Examination of cores from A.A.O. No. 1 (Roma) well, and of cuttings from A.A.O. No. 5 (Hospital Hill) well has revealed that lithologies similar to those outcropping occur in the intervals 770-1,250 ft. in the former, and 720-1,115 ft. in the latter. In the writer's interpretation of the log of A.R.O. No. 10 (Orallo) well, which was sited near the top of the Formation, the unit is represented by the strata in the interval penetrated from 0-350 ft. This indicates an apparent dip to the south-east of about 60 ft, per mile from the vicinity of Hunterton (elevation 1,280 ft.), where sediments near the base of the Formation are exposed.

There is considerable lateral and vertical variation in the outcropping sediments. In the type area the earliest sediments are micaceous silty shales and siltstones, with some interbedded calcareous protoquartzites, well exposed in Bungeworgorai Creek at m.r. 673736, Mitchell 4-mile military map. These closely resemble sediments of the Injune Creek Beds. In Appletree Creek, at m.r. 195726 and m.r. 196726, the basal sediments are fine-grained, calcareous protoquartzites, with lenses of silty shale, while near Mooga Creek at m.r. 165732, and near the Wallumbilla-Taroom road at m r. 209734 and m.r. 209736, they are medium-grained subgreywackes. At m.r. 195726 and m.r. 209734 small, impersistent lenses of conglomerate occur at the junction with the underlying Gubberamunda Sandstone.

In thin section the fine-grained, thin-bedded, calcareous protoquartzites exposed in the Hunterton-Orallo area show 75-80 per cent. quartz, 13-15 per cent. lithic fragments, and 7-10 per cent. feldspar. The quartz is quite angular, and at least 20 per cent. of it shows strain extinction. The feldspars are mostly angular, fresh, lath-shaped plagioclase, with some sericitised, rounded plagioclase, and a little perthite. The lithics are mostly rounded argillite fragments, with some andesitic fragments also.



Calcareous concretions in sandstones of the Orallo Formation in Bungeworgorai Creek at Johnson's Crossing (m.r. 136725).

In the type area these fine-grained lithologies are overlain by friable, medium- to coarse-grained subgreywackes, outcropping near Bungeworgorai Creek at m.r. 133732 and m.r. 132730. Outcrops of similar sediments are widespread, and this lithology is characteristic of the Formation. As noted previously, such subgreywackes are not restricted to the middle part of the unit, as in the type area. Impersistent conglomerate lenses are of frequent occurrence and the surface is commonly strewn with pebbles, cobbles, and fragmentary silicified fossil wood, weathered from them. About half of the pebbles and cobbles are white and grey quartz; the remainder comprise quartzites, argillites, fine-grained andesitic and trachytic rocks, quartz-feldspar porphyries, and rare coarse-grained granitic rocks. All are well rounded. Fragmentary fossil wood is also abundant, but large trunks are rare. Some of the fragments are water-worn and could be remanie fossils.

In thin section the subgreywackes show 60-70 per cent. quartz, 20-25 per cent. lithics, and 10-15 per cent. feldspar. At least 20 per cent. of the quartz exhibits strain extinction. The larger quartz grains are moderately well rounded; the smaller quite angular, though usually subequant. The lithic clastic grains are well rounded, the bulk of them being argillaceous rock fragments which look like chert in the hand specimen; the remainder are of andesitic or trachytic composition. Feldspars are mostly fresh, subangular plagioclases, with some microcline and perthite. Apart from fontainebleu sandstone concretions calcareous cements have only a limited distribution. Mechanical analyses of these sands show they are very well sorted and virtually free of matrix.

The medium to coarse grain size, good sorting, and lack of matrix and cement in these subgreywackes are features which make them excellent aquifers, and it is probably their equivalents that form the prominent aquifer logged in the Hospital Hill oil wells between approximately 900 and 1,000 ft. Here this aquifer is in turn overlain by 100 to 200 ft. of shale with coal, and fine-grained quartzose sandstone, which is coarse in its basal parts. This is the sequence seen in outcrop in the Mooga Mooga Creek area, where the change

from shale with coal to quartzose sandstone with conglomerate lenses coincides with the base of the "Mooga Sandstone" as mapped by Reeves (1947). For this reason the present subsurface interpretation is preferred to that of Reeves, who showed (figs. 9 and 11) the aquifer in this interval in the Hospital Hill wells as "Mooga Sandstone". Interpretation of Reeves' "Mooga Sandstone" is further considered in the section on the Blythesdale Formation.

In the type area the upper part of the Formation consists dominantly of shales, which are carbonaceous in part. At m.r. 137724, in Bungeworgorai Creek, a section 70 ft. thick is exposed. The sediments here are claystones, very carbonaceous shales with lenses of bright coal, and clayey, carbonaceous siltstones, with minor interbedded, medium-grained, feldspathic subgreywacke. Further downstream, at m.r. 139723, the boundary with the Blythesdale Formation is exposed in the south bank. Here carbonaceous shales at the base of the section are overlain by 7 ft. of intertonguing lenses of carbonaceous shale and medium- to coarse-grained protoquartzite with pebbly patches. These in turn are overlain by 1-3 ft. of white quartz pebble conglomerate, which grades upwards into medium- and coarse-grained protoquartzites and orthoquartzites, which have pebbly lenses. A similar sequence is exposed in Mooga Mooga Creek at m.r. 160717.

This essentially shaly sequence at the top of the Orallo Formation is probably represented in the shaly interval with coals, reported in A.A.O. Nos. 4 and 5 (Hospital Hill) wells, from 720-890 ft. and 730-825 ft. respectively, and called "Fossil Wood Stage" by Derrington and Hammett (1960). In A.A.O. No. 3 (Roma) well similar sediments were reported by Mott (1960) from the interval 385-535 ft. Their shallower depth here is explained by the fact that this well and the adjacent ones, A.A.O. No. 2 (Roma) and R.B.O. Nos. 1 and 4 (Mt. Bassett), penetrated sediments of the Kingull Member from surface to approximately 200-250 ft.

All of the known coals of the Orallo Formation are thin, most of them being concentrated in the topmost 100 ft. of the Formation. Cameron (1913) reported on those exposed at or near the base of the section in Bungeworgorai Creek, in Portion 60v, Parish of Bengalla, where an attempt was made to work them. Jensen (1926b) discussed Cameron's report and called these sediments the "Yingerbay Coals". In the lower part of the Formation coal and kerosene shale were reported by Jensen (1926b), from an outcrop near the junction of Bungeworgorai and Stewart Creeks.

Environment of Deposition

Changes in the depositional environment of the Orallo Formation are reflected in the lateral and vertical variations in its sediments. In the finer grained sediments, the grain size and sedimentary structures (thin bedding and simple cross-beds of McKee, 1957) suggest deposition under quiet, shallow-water conditions, with the abundance of calcareous material perhaps indicative of ponding and drainage restriction, and the presence of coals suggesting reducing conditions. Their depositional environment seems to have been a restricted lacustrine one. Similar conditions must have prevailed during the deposition of the Injune Creek Beds and the Kingull Member, as these sediments closely resemble the finer lithologies of the Orallo Formation. The sediments of all these are typical of the "calcareous facies" of Whitehouse (1953).

The coarser grained sediments, with their associated conglomerate lenses and planar and trough cross-beds (McKee, 1957), reflect more boisterous, possibly fluviatile depositional conditions.

The interplay of these two sets of conditions has resulted in fairly rapid alternations of shales and sandstones, with both lithologies lacking lateral persistence. This suggests that the overall environment may have been that of a valley-flat, with local ponding, and in general, with the rate of subsidence being balanced by the rate of sedimentation. Later this balance was disturbed, apparently by an increase in the rate of subsidence, and the environment replaced by a more uniform lacustrine one, in which the basal sediments of the Blythesdale Formation were deposited.

Palaeocurrent directions, indicated by the cross-beds, all lie within the north-west to north-east quadrant. Of these the north-westerly one is the most prominent, and clear evidence of it can be seen in an exposure in Bungeworgorai Creek at Johnson's Crossing (m.r. 136725), where the creek has cut across the strike of sets of planar cross-beds, the cross-bedding dipping unidirectionally south-eastwards at angles of 17°-25°. This palaeocurrent direction may have been that of a drainage feature, but it is not possible to say whether it is of more than local significance.

The high percentage of metamorphic quartz and lithic fragments suggests a provenence of pre-existing lithic sandstones for these sediments. The roundness of the lithic fragments indicates renewed transport; the greater angularity of the quartz probably resulting from its greater resistance of abrasion.

Age and Stratigraphic Relationships

The Orallo Formation conformably overlies the Gubberamunda Sandstone, and is overlain in apparent conformity by the Blythesdale Formation. In the headwaters of Appletree and Yuleba Creeks on the Great Dividing Range the Formation is unconformably overlain by Tertiary lateritised sandstones.

The age of this Formation is difficult to determine precisely, but, as the top of it is less than 500 ft. stratigraphically below the base of the Roma Formation of Aptian age in an apparently conformable succession, an uppermost Jurassic age seems likely. The base of the Blythesdale Formation is arbitrarily considered as the base of the Cretaceous sediments in this area.

Plant fossils have been found in shales near the base and near the top of the Formation. Whitehouse (1927) recorded *Taeniopteris spatulata* McClelland, *Cladophlebis australis* (Morris), *Ginkgoites* cf. *digitata* (Brongniart), *Elatocladus* sp. and *Podozamites* sp. from the junction of Bungeworgorai and Stewart

Creeks, near the base of the Formation. In addition, *Elatocladus plana* (Feistmantel) and *Pterophyllum fissum* Feistmantel are now recorded from this locality. Willcox (1926) recorded *Cladophlebis australis* (Morris) and *Taeniopteris spatulata* McClelland from Shanahan's farm, 25 miles N.N.E. of Roma. De Jersey (1959) recorded *Dicroidium feistmanteli* (Johnston) and *Podozamites* sp. from Bungeworgorai Creek 21·5 miles by road from Roma. Clays exposed at this locality (m.r. 137724), near the top of the Formation, have yielded, in addition, *Cladophlebis australis* (Morris), *Elatocladus plana* (Feistmantel), and *Equisetites* sp. The form identified by de Jersey as *D. feistmanteli* was tentatively determined by Dr. J. Townrow (pers. comm.) as *Halleophyllum crassum* (Halle). *H. crassum* is present in collections of the Geological Survey of Queensland from the Injune Creek Beds at Bymount, but has not been found in the Blythesdale Formation. Its occurrence at this locality and at Bymount was also noted by Whitehouse (1955, p.10), who referred to the form as *Thinnfeldia feistmanteli*. Of the other species, only *Podozamites* sp., a narrower form than that described from the post-Aptian Burrum Coal Measures by Walkom (1919) as *P. lanceolatus* (Lindley and Hutton), does not occur in the Blythesdale Formation. However, the flora is too imperfectly known at present to be of much use for correlation and age determination.

Blythesdale Formation

This replaces the name Blythesdale Braystone of Jack (1895a, b). There has been considerable confusion concerning the use of the name, and an attempt has been made to show in tabular form the interpretations of various authors (Table 2).

TABLE 2

COMPARISON OF THE USAGE OF THE STRATIGRAPHIC NAME BLYTHESDALE

Diagrammatic only

JACK 1895	ROLLING DOWNS FORMATION: SHALY PART OF ROLLING DOWNS FORMATION	BLYTHESDALE BRAYSTONE		IPSWICH FORMATION	DESERT SANDSTONE
RANDS 1901	ROLLING DOWNS FORMATION	BLYTHESDALE BRAYSTONE		IPSWICH FORMATION	
SAINT-SMITH 1914	ROLLING DOWNS FORMATION: BLYTHESDALE BRAYSTONE	TRIAS-JURA OR WALLOON			
PITTMAN 1914 - 1916	ROLLING DOWNS FORMATION: BLYTHESDALE BRAYSTONE	TRIAS-JURA INCLUDING MISNAMED BLYTHESDALE BRAYSTONE			
DUNSTAN 1916	ROLLING DOWNS MARINE SERIES: BLYTHESDALE BRAYSTONE	WALLOON SERIES			
JENSEN 1926	LOWER CRETACEOUS MARINE	UPPER WALLOON		MIDDLE WALLOON	
BALL 1927	LOWER CRETACEOUS MARINE	TRANSITION BEDS		WALLOON COAL MEASURES	
REEVES 1947	ROMA SERIES	TRANSITION STAGE OR SERIES	MOOGA SANDSTONE	FOSSIL WOOD STAGE OR SERIES	GUBBERAMUNDA SANDSTONE
WHITEHOUSE 1955	ROMA FORMATION	BLYTHESDALE GROUP: TRANSITION BEDS	MOOGA SANDSTONE	FOSSIL WOOD BEDS	GUBBERAMUNDA SANDSTONE
JENSEN 1960	CRETACEOUS	BLYTHESDALE BRAYSTONE OR TRANSITION BEDS	MINKA BEDS	UPPER SILICIFIED WOOD SANDSTONE	ORALLO COAL MEASURES / LOWER SILICIFIED WOOD SANDSTONE
DAY This publication	ROMA FORMATION	BLYTHESDALE FORMATION: MINMI MEMBER	NULLAWURT SANDSTONE MEMBER / KINGULL MEMBER	MOOGA SANDSTONE MEMBER	ORALLO FORMATION / GUBBERAMUNDA SANDSTONE

In proposing the name Blythesdale Braystone, Jack (1895a, p.6) stated, "In mapping the eastern limit of the Lower Cretaceous Formation, we find that at the base there is a series of soft, grey, very friable sandstones, grits, and conglomerates . . . To this rock we felt it necessary to give a distinctive name, the "Blythesdale Braystone", as it is well developed at Blythesdale, near Roma, . . ." Later, Jack (1895b) provided additional information on the unit and it appears on the map of Jack and Maitland (1895). It is quite evident that when Jack proposed the unit and specifically mentioned Blythesdale he did

not mean Blythdale Siding, but the old Blythesdale Homestead, which was situated about 2 miles north-east of the siding (m.r. 180699).

Until 1914 authors used the name Blythesdale Braystone in much the same sense as Jack. The only innovation was that of Rands (1901, p.246), who dissociated the unit from the Rolling Downs Formation. This involved no change in the concept of the unit, and until 1914 the Blythesdale Braystone was regarded as a Lower Cretaceous aquifer "series" underlying the marine "Rolling Downs Formation".

Confusion began when Saint-Smith (1914) restricted the Blythesdale Braystone to the marine sediments outcropping near Blythdale Siding. (In the present interpretation these comprise the topmost 50-70 ft. of the Blythesdale Formation, that is, the Minmi Member). Similar sediments to the north, which, as he mentioned (p.20) were included in the unit by Jack, were excluded, apparently because they were of freshwater origin. Pittman (1914, 1915, 1917) drew attention to this, but both he and Saint-Smith erred in their restriction of the scope of the formation. Pittman (1915, p.11), interpreting the unit as the basal *bed* of the "Rolling Downs Formation", regarded the term Blythesdale Braystone as a misnomer and recommended that it be abandoned. Dunstan (1916), following Saint-Smith's interpretation, did not use the term, while Reid (1929) stated that the Geological Survey of Queensland had abandoned the term as it had no stratigraphic significance. The name virtually lapsed until it was resurrected by Whitehouse, but was used without discussion or definition by Bryan and Jones (1946), by David (1950) as "Blythesdale Series" and on the Geological Map of Queensland (1953) as "Blythesdale Sandstone".

Whitehouse (1955, p.9) discussed the history of this unit in some detail and concluded that the stratigraphic name Blythesdale should, by priority and aptness, be retained. He quoted the type area as "along Blyth Creek, a few miles north of Blythdale railway station". However, his usage of the term Blythesdale in the sense of the Blythesdale Group, comprising the "Gubberamunda Sandstone" together with the "Fossil Wood Stage or Series", the "Mooga Sandstone", and the "Transition Stage or Series" of Reeves (1947), is at variance with the original concept of Jack and, consequently, with that adopted here. The map of Jack and Maitland (1895) shows the Blythesdale Braystone outcropping in the Blyth Creek area from just north of Blythdale Siding, northwards as far as the junction of Blyth and Twelve Mile Creeks. North of this to the Great Dividing Range, "Ipswich Formation" is shown, while the area straddling the Great Divide is mapped as "Desert Sandstone". Recent examination of this area has revealed that the Blythesdale Braystone as mapped here by Jack and Maitland is a readily definable, mappable unit; their "Ipswich Formation" approximates to the Orallo Formation; and their "Desert Sandstone" roughly represents the sandy outcrop belt of the Gubberamunda Sandstone, although it includes some Tertiary sediments as well. Clearly the sediments constituting these two Formations, the Orallo Formation and the Gubberamunda Sandstone, were excluded from the Blythesdale Braystone by Jack.

The priority of Jack's usage must be accepted, and in the proposed stratigraphic subdivision this unit is given formational status. As a number of sediment types, some of which show lateral variation are present, the name Blythesdale Formation is used. A new group name to cover the Blythesdale Formation, Orallo Formation, and Gubberamunda Sandstone is not considered desirable, because collectively, they do not constitute an entity of lithogenetic significance.

The type locality of the Formation is here designated as the area near Blyth Creek, extending from 0·5 mile north of its junction with Twelve Mile Creek, to 1 mile south of Blythdale Siding; that is, between m.r. 191715 and m.r. 178695. The lower boundary is placed a little to the north of that shown on the map of Jack and Maitland (1895), while the upper one is located slightly further to the south. The Formation derives its name from the old Blythesdale Homestead. It is estimated that about 50 per cent. of the thickness is exposed in the type area.

Whitehouse (1955, p.9) reported that the Blyth Creek section was not easy to interpret, as Tertiary sandstones also are common there. Upper Cainozoic sediments do form quite prominent outcrops in this creek, although generally their unconformable relationship can be recognized, and where this is not evident they can be readily distinguished by their less coherent nature and by the presence of billy pebbles.

On one of the maps of Jensen (1926a, p.51) the "Upper Walloon" in the Blyth Creek area approximates to the Blythesdale Formation, but on another (1926b, pl. 1) it includes much of the underlying Orallo Formation as well. In a revision of his work Jensen (1960) recognized three units at the top of the "Upper Walloon":—in descending order, "Transition Beds or Blythdale Braystone", "Minka Beds", and the "Upper Silicified Wood Stage or Sandstone". These are equivalent to the Blythesdale Formation.

If the "Mooga Sandstone" of Reeves (1947) is interpreted on the basis of his mapping within the Parish of Mooga, then the Blythesdale Formation is equivalent to the "Mooga Sandstone", together with his "Transition Stage or Series" and the friable marine sandstones which he regarded as basal sediments of the Roma Formation. The "Transition Beds" of Ball (1927a, p.94), as interpreted from his sketch map (1927b, p.143), are also approximately equivalent to the Blythesdale Formation.

The physiography of the outcrop area is quite distinctive, the terrain generally being broken, whereas that associated with the Orallo and Roma Formations is more undulating. In the area adjacent to Bungeworgorai and Bungil Creeks, there is a well developed escarpment formed by the lower beds of the formation. Elsewhere this section forms flat-topped ridges and buttes. The top of the Formation is mapped on the change from a steeply gullied topography to a "rolling

downs" type and on the change from red sandy soils to black clayey ones associated with the Roma Formation.

Thickness and Lithology

As with the other formations in this area, incomplete exposure and low dips make estimates of thickness difficult. Jack (1895a, p.8) commented ". . . apparent dips have proven unreliable, so that I have no confidence in any estimate of the total thickness of strata represented by the outcrop. I incline to the belief that on the whole the angle of dip is very low—perhaps in many instances no more than the fall of the ground". He considered 460 ft. would not be an overestimate. The thickness of the Blythesdale Formation is now estimated at 500-550 ft. Jensen (1926b) suggested a thickness of 400-500 ft. for his "Upper Walloon", but later (1929) doubled this estimate. The aggregate of the estimated thicknesses of the three new subdivisions (=Blythesdale Formation) at the top of his revised (1960) "Upper Walloon" is 1,100 ft. Ball (1927a) estimated the thickness of the "marine Cretaceous" in the Hospital Hill wells at 800 ft., but apparently this includes his "Transition Beds" too, for Ball is quoted by Jensen (1929) as regarding the sediments in the interval 200-780 ft. in the R.O.C. No. 1 (Hospital Hill) well as "Transition Beds". This closely agrees with the present interpretation. The figure of 700-800 ft., obtained by adding the estimated thicknesses of the "Mooga Sandstone" and the "Transition Stage or Series" of Reeves (1947) (=Blythesdale Formation), is an overestimate, possibly resulting from Reeves' correlation of the "Mooga Sandstone" with the aquifer occurring in the interval 900-1,000 ft. in the Hospital Hill wells.

In the oil wells drilled in this area the Formation seems to be 500-550 ft. thick. Where the base of the Formation is exposed in Bungeworgorai Creek at m.r. 139723, and in Mooga Mooga Creek at m.r. 160717, there is a pronounced change in lithology from carbonaceous shales to fine- and medium-grained quartzose sandstone, which is often quite coarse and conglomeratic in its basal section. As a similar change in lithology can generally be recognized in the oil wells of the area, the base of the Formation can usually be identified without difficulty. The top of the Formation is harder to establish, as the Blythesdale grades upwards into the Roma Formation. Examination of core from Builders Ltd. Roma No. 1 Scout bore, which was drilled on Hospital Hill, has shown that Roma Formation shales with minor silty bands extend from 0-189 ft. Below this, there is about 90 ft. of glauconitic sandstone and minor shale; with marine fossils. Probably the top of the Formation in all the Hospital Hill wells was penetrated at about 200 ft. The base of the Formation in A.A.O. No. 5 (Hospital Hill) well, as interpreted from an examination of cuttings, probably occurs at about 730 ft., indicating an apparent dip of about 66 ft. per mile S.10°W. from the base of the Formation in Mooga Mooga Creek (elevation 1,040 ft.). This depth of 730 ft. was reported as the base of the "Mooga Sandstone" by Derrington and Hammett (1960). An examination of cores from A.A.O. No. 1. (Roma) well has revealed a sequence similar to that in A.A.O. No. 5 (Hospital Hill) well, the Blythesdale Formation being represented in the interval 200-770 ft., which was referred to the Blythesdale Group by Mott (1960). No Roma Formation is present in the oil wells drilled near Blythdale, but as they were sited very close to the upper boundary of the Blythesdale Formation and the regional dip is low, the sequence they penetrated is almost complete. From an interpretation of the drillers' logs of R.O.C. No. 4 (Blythdale) and A.R.O. Nos. 4, 5 and 11 (Blythdale) wells, the Formation seems to extend from surface to approximately 500-550 ft.

Jack (1895a, b) described the lithologies of the Formation as soft, grey, very friable sandstones, grits and conglomerates, parted in places by beds of sandy shale and calcareous sandstone. Jensen (1926b) stated that the "Upper Walloon" comprised fine-grained, porous, siliceous sandstone and interbedded, often carbonaceous shales. Ball (1927a) recorded the lithologies of the "Transition Beds" as sandstone, mudstone, and impure limestone. Reeves (1947) gave the lithologies of the "Mooga Sandstone" as fine- to medium-grained sandstone and sandy shale, with a quartz pebble conglomerate near the base, and those of the "Transition Stage or Series" as soft, arkosic sandstone, grey, sandy clay shale, and lenses of coal. Evidence of lateritisation of the Blythesdale sediments is confined to a few elevated remnants in the eastern part of the area.

The Blythesdale Formation can be conveniently subdivided into four:—the Mooga Sandstone, Kingull, Nullawurt Sandstone and Minmi Members, of which the uppermost (Minmi Member) is marine, and the remainder freshwater. The type areas of these members are here designated:—

Mooga Sandstone Member: Parish of Mooga in the area near the junction of Bungil and Mooga Mooga Creeks, extending from 1·5 miles north of where the main Roma-Injune road crosses Bungil Creek, southwards to a point approximately 1 mile south of this crossing; that is, between m.r. 159718 and m.r. 159714.

Kingull Member: The area near Bungeworgorai Creek extending from about 1 mile north of Kingull Siding (m.r. 144717), southwards to where the Roma-Orallo road crosses this creek. Also included are the underlying sediments of the section exposed in Bungeworgorai Creek at m.r. 142713, and those of railway cuttings at m.r. 144714, m.r. 145713 and m.r. 145712.

Nullawurt Sandstone Member: The area near the Injune Railway line extending from 0·25 mile south of Kingull Siding, southwards as far as Nullawurt Siding; that is, between m.r. 144716 and m.r. 145711. In sections between m.r. 144716 and m.r. 145712 the junction with the underlying Kingull Member is exposed, and only the uppermost sediments of these sections are included.

Minmi Member: The area near Bungil Creek at Minmi crossing (m.r. 162706) extending approximately 0·5 mile north and south of the crossing.

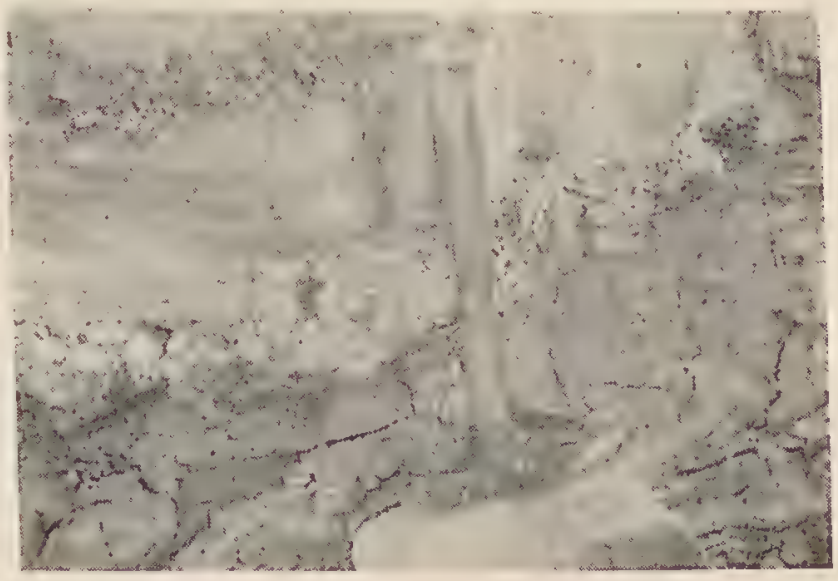
Mooga Sandstone Member

The lowest subdivision, the Mooga Sandstone Member, is regarded as equivalent to the "Mooga Sandstone" of Reeves (1947). This interpretation is based on Reeves' description and map of the unit in the Parish of Mooga. The Member can be recognized in the area along Blyth Creek, where it outcrops from 0·5 mile north of the junction of Blyth and Twelve Mile Creeks, southwards to a point about 1 mile south of the junction of Blyth and Ferguson Creeks. Its outcrop area is characteristically more elevated than the surrounding country and its base is frequently escarpmented. The "Upper Silicified Wood Sandstone" of Jensen (1960) is approximately equivalent to the Mooga Sandstone Member.

Base of the Blythesdale Formation (Mooga Sandstone Member) exposed in Mooga Mooga Creek at m.r. 160717.

Reeves (1947) estimated the thickness of the "Mooga Sandstone" as 150-200 ft., and this is in accord with that made here. In the type area the sediments exposed are about 150 ft. thick, while at the northern end of the Grafton Range, near Mount Saltbush Homestead, about 200 ft. are exposed. The outcropping sediments are dominantly grey to yellowish-brown, fine-grained orthoquartzites and protoquartzites, with minor argillaceous sandstones, micaceous and carbonaceous siltstones, and silty shales. They are frequently calcareous, and thin beds of argillaceous limestone and deposits of white dolomitic material on joints and bedding planes are common. Fontainebleu sandstone concretions also are common. Lenses of white quartz pebble conglomerate occur in the basal section of the Member, and the orthoquartzites and protoquartzites here often have coarse-grained and pebbly patches concentrated in the bottoms of trough cross-beds. The orthoquartzites resemble those of the Nullawurt Sandstone Member, but in general they are coarser grained.

An examination of cuttings from A.A.O. No. 5 (Hospital Hill) well has shown that sediments similar to those outcropping occur in the interval 510-730 ft. These strata were reported as "Mooga Sandstone" by Derrington and Hammett (1960). This differs from the interpretation of Reeves (1947, figs. 9 and 11), in which the base of the "Mooga Sandstone" in the Hospital Hill wells was located at about 1,000 ft. In A.A.O. No. 3 (Roma) well, which was sited in the Kingull Member and so penetrated an incomplete Blythesdale section, the Mooga Sandstone Member is probably represented by the water-bearing sandstone reported from the interval 245-385 ft. by Geological Survey of Queensland (1960). From an interpretation of the drillers' logs of the Blythdale oil wells, the Mooga Sandstone Member seems to occur in the interval 300-550 ft. The Member is frequently water-bearing in the wells of the area, but it is not as prominent an aquifer as the Gubberamunda Sandstone or some of the sands of the Orallo Formation.



Pebble conglomerate at the base of the Blythesdale Formation (Mooga Sandstone Member) in Mooga Mooga Creek at m.r. 160717.

Cross bedding in the Mooga Sandstone Member of the Blythesdale Formation in Mooga Mooga Creek at m.r. 160717. Cross beds dip south-east.

In thin section the protoquartzites show up to 25 per cent. well rounded feldspar and lithic fragments, like those of the underlying Orallo Formation. The quartz grains are mostly elongate to subequant and rather angular, especially the smaller ones. At least 50 per cent. of the quartz displays strain extinction and overgrowths occur occasionally. Graded bedding of a seasonal type is also present. Frequently matrix and cement are virtually absent. The orthoquartzites are similar, but have more quartz. In thin section the argillaceous limestones show 75-85 per cent. recrystallised calcite. The remaining 15-25 per cent. is comprised largely of quartz in small, extremely angular, widely separated grains.

Mechanical analyses of numerous orthoquartzite and protoquartzite samples show they are well sorted with sorting coefficients (So.) 1·15-1·40. Most have less than 10 per cent. matrix. By contrast, the sands of the overlying Kingull Member have poor sorting and more matrix.

Kingull Member

The Kingull Member, which in general is poorly exposed, is about 200 ft. thick. It roughly approximates to the "Minka Beds" of Jensen (1960), which however, also include the Nullawurt Sandstone Member. Jensen's name is not a good one as Minka Siding lies 5 miles south of the area of outcrop. The Member outcrops intermittently along Blyth Creek from about 1 mile south of the junction with Ferguson Creek, downstream as far as the junction with Myall Creek. The sediments exposed are highly calcareous, grey, micaceous siltstones, with cone-in-cone limestone in some places, silty and clayey, grey and brownish carbonaceous shales, and grey, fine- and medium-grained calcareous subgreywackes in rapid alternation. Ironstone concretions are numerous and form bands in some places.

In A.A.O. Hospital Hill wells the Kingull Member is probably represented by the grey mudstones, shales, fine-grained calcareous and argillaceous sandstones, and thin impure limestones reported as "Transition Stage" by Derrington and Hammett (1960) from the intervals 290-535 ft. in A.A.O. No. 4 and 290-505 ft. in A.A.O. No. 5. In A.A.O. No. 3 (Roma) well the Member is probably represented in the section with thin coal bands, penetrated from 0-245 ft. and called Roma Formation by Mott (1960). Examination of the log of A.R.O. No. 4 (Blythdale) well suggests that the Member occurs in the interval 102-297 ft.

In thin section the subgreywackes show 65-75 per cent. angular quartz, about half of which displays strain extinction. Lithic fragments amount to another 20-25 per cent. of the clastic fraction, the remainder being feldspar. The lithics are well rounded argillite fragments and a few ironstone grains. Nearly all the feldspar is fresh, lath-shaped plagioclase; microcline and perthite occur only in minor amounts. Calcareous cement may form up to 30 per cent. of the rocks.

Mechanical analyses show that the subgreywackes have more matrix than the sands of the underlying Mooga Sandstone Member and are not as well sorted.

Rail cutting just north of Yingerbay (m.r. 144714) showing cross bedded sandstones of the Kingull Member overlain by the Nullawurt Sandstone Member.

Nullawurt Sandstone Member

The junction of the Nullawurt Sandstone Member with the shaly Kingull Member is well exposed in a rail cutting 0·25 mile north of Yingerbay Siding (m.r. 144715) and in Blyth Creek 0·25 mile downstream from the junction of Myall Creek (m.r. 182701). Here the basal sediments are non-calcareous, yellowish-brown, fine- to very fine-grained orthoquartzites, with occasional thin grey shale partings. Worm tracks, burrows, and ? coprolites are abundant, and plant fossils and freshwater pelecypods occur occasionally. As the immediately overlying sediments contain marine fossils, these are the youngest freshwater Blythesdale sediments of the area. Jensen (1926b, p.45) stated that these were the topmost sandstones of the "Walloon" and called them the "Nullawurt Horizon," deriving the name from the old Nullawurt Siding (m.r. 145711), where they outcrop on low ridges. The name Nullawurt Sandstone Member replaces this name. These sediments are about 50 ft. thick and form a distinctive marker in the field.

An examination of cores from the A.A.O. No. 1 (Roma) well has shown that sediments similar to those outcropping occur in the interval 280-300 ft. (core 5). In the Hospital Hill wells the Member is not as well defined, but probably occurs in a similar depth interval. The sediments logged as sandy shale in the interval 30-102 ft. in the A.R.O. No. 4 (Blythdale) well, may represent the Nullawurt Member.

In thin section the orthoquartzites of the Nullawurt Sandstone Member show few minerals other than quartz. The quartz grains are elongate to equidimensional, and very angular.

About half of them display strain extinction. Occasional rounded argillite fragments occur, together with magnetite and rutile. There is very little matrix. Mechanical analyses show that the sorting of the orthoquartzites is very good, with sorting coefficients (So.) 1·15-1·30.

Minmi Member

The freshwater beds are overlain by 50-70 ft. of marine Blythesdale sediments (the Minmi Member), which are well exposed at Minmi crossing (the type area) and near the old Blythesdale Homestead. Saint-Smith (1914), when he restricted the Blythesdale Braystone of Jack (1895a, b) to these sediments, showed their thickness as 140 ft. on his cross section. The "Blythdale Braystone" or "Transition Beds" of Jensen (1960) is also approximately equivalent to the Minmi Member, although his figure of 500 ft. for their thickness is a gross overestimate.

The distribution of outcrop is largely controlled by topography. In the elevated area along the Grafton Range, outcrops of marine sediments have been observed as far north as the head of Sleepy Creek, while in the lower lying country between Warooby and Blyth Creeks outcrops occur more than a mile south of the Western Railway.

Saint-Smith (1914) described these sediments as "highly calcareous sandstones containing abundant marine shells, bands of grey sandy shale, and occasional thin beds of blue shale, the sandstones constituting by far the greater proportion of the rocks". The exposed sediments are dominantly fine- and medium-grained, calcareous and glauconitic protoquartzites, which often have clayey shale fragments, coarse-grained lenses and bands, and large ovate fontainebleu sandstone concretions. In places marine fossils and fossil wood are abundant. Minor clayey and silty shales, and siltstones are also common, and thin intraformational mud-pebble conglomerates occur occasionally, the last mentioned being especially well develpoed in the type area.

Ripple marked sandstone of the Minmi Member of the Blythesdale Formation exposed on Red Hill at m.r. 161706.

—Photo. P. J. Conaghan.

An examination of cores from Builders Ltd. Roma No. 1 Scout bore drilled on Hospital Hill, has shown that sediments similar to those outcropping occur in the interval 189-280 ft. The "light coloured marker sandstone with carbonised plant impressions" reported by Ball (1928, p.396) from the interval 189-238 ft. in this bore is a part of the Minmi Member, as this sandstone is glauconitic. The sediments of core 4 (216-233 ft.), from A.A.O. No. 1 (Roma) well are similar and the Minmi Member is probably represented in the interval 200-280 ft. in this well. The Builders Ltd. Beaufort Scout bores, reported on by Ball (1931), were all sited on the Minmi Member and, on the basis of Ball's figure and the evidence from fossiliferous pieces of core, sediments of this Member seem to extend from surface to about 80 ft., although glauconitic sandy mudstones are recorded from as deep as 100 ft. The sediments as logged by Ball (1931) are dominantly ferruginous and gypseous sandstone, with minor ferruginous sandy mudstones, shales, and lenses of calcareous sandstones 5-10 ft. in thickness. Their lenticularity is clearly shown in Ball's figure (p.10). The underlying 60-80 ft. of sandy mudstone with small lenses of carbonaceous shale containing plant fossils may represent the Nullawurt Sandstone Member.

Thin sections of the friable protoquartzites show 70-80 per cent. of the clastic fraction is rather angular quartz, about 20 per cent. of which displays strain extinction. The remaining 20-30 per cent. of the clastic fraction is composed of rounded green grains of glauconite (10-15 per cent.), rounded argillite and quartzose sandstone fragments (7-10 per cent.), fresh lath-shaped plagioclase feldspar (3-5 per cent.), and occasional coal fragments. The cemented protoquartzites have up to 40 per cent. calcite as cement. Apart from the glauconite, the mineralogy of these marine Blythesdale sediments is rather like that of the underlying freshwater ones.

Mechanical analyses of fine-grained friable samples show they are well sorted, with sorting coefficients (So.) 1·15-1·30, like those of the immediately underlying sands, but differing from them in their coarser grain size. The medium-grained samples have poorer sorting (So., 1·33-1·50).

Environment of Deposition

A considerable variety of depositional environments are represented in the Blythesdale Formation.

The good sorting and trough cross-bedding of the quartzose sands of the Mooga Sandstone Member are indicative of deposition in shallow water by rapidly flowing currents. Palaeocurrent directions shown by cross-beds are somewhat variable, but the bulk lie within the north-east to north-west quadrant. Drainage

was apparently largely unrestricted, though quieter conditions prevailed during the deposition of the finer, silty lithologies. Conditions of sedimentation were fairly uniform throughout the area as the quartzose sandstones of this Member have considerable lateral persistence. The environment presents a distinct contrast to that prevailing during the deposition of the underlying Orallo Formation.

Following deposition of the Mooga Sandstone Member conditions of sedimentation changed. The dominance of finer lithologies (silts and shales) and poorer sorting of the sands in the Kingull Member suggest deposition in quiet water by slow moving currents, while the abundance of carbonaceous and calcareous material suggest reducing conditions and restricted drainage. Probably these sediments were deposited in a restricted lacustrine environment, which ceased before the deposition of the basal orthoquartzites of the Nullawurt Sandstone Member.

The Nullawurt orthoquartzites have current ripple marks and gently dipping (8°) cross-beds. The latter are occasionally extremely persistent, foreset beds up to 20 ft. long being observed. According to McKee (1957) this type of cross-bedding is a feature of sandy beach deposits. However, in this case, the environment must have been very sheltered, as quiet, shallow-water conditions of sedimentation are indicated by the fine grain size, thin bedding, good sorting and the preservation of abundant animal tracks and burrows. The environment was apparently fairly uniform over a wide area as these sediments have lateral persistence like the sands of the Mooga Sandstone Member. Possibly they represent a sheltered, near-shore, lacustrine environment. Some south-westerly palaeocurrent directions are indicated by the current ripple marks, but those indicated by the cross-bedding are more variable, between east-south-east and west-north-west.

With the subsequent onset of marine conditions, a strand zone must have existed. However, no strand line sediments have been recognized, nor has lateral gradation from freshwater to marine been observed in the area of study.

The presence of ripple marks like those of intertidal areas, animal trails, and thin intraformational mud-pebble conglomerates, together with the abundance of burrowing pelecypods and fossil wood, indicate a very shallow-water, near-shore environment. Fossil rain prints reported in these sediments by Ball (1927b, p.141) provide additional evidence, and the occurrence of beds of disarticulated shells is also in accord with this interpretation. Sets of cross-beds 6 to 9 in. thick, with foreset beds 1 to 2 ft. in length and dipping at 10° to 18°, are extensively developed. Cross-bedding of this scale and type is cited by McKee (1957) as a feature of lower foreshore or backshore deposits. In Clerk Creek at m.r. 141702, there is an exposure of marine sandstones with a set of planar cross-beds 3 to 4 ft. thick, the inclined beds dipping north-east at 25°, indicating a palaeocurrent from the south-west. Cross-bedding of this type is fairly rare in these sediments. The palaeocurrent directions indicated by ripple marking are consistently from the south-west and this direction is commonly observed in the small scale cross-beds, although here the directions tend to be more variable.

This environmental interpretation would require some of the marine Blythesdale sediments to be near-shore facies equivalents of sediments in the lower part of the Roma Formation. Faunal evidence does not conflict with this and many of the faunal differences could well be ecological.

Age and Stratigraphic Relationships

The relationship between the Blythesdale Formation and the Orallo Formation is not apparent; but there is a pronounced lithological change from carbonaceous shale with coal at the top of the underlying Formation to coarse-, medium-, and fine-grained orthoquartzites and protoquartzites which may indicate disconformity. However, at present it is not possible to say whether this change in sedimentation involved any significant time break. The change from the marine sediments of the Blythesdale to those of the Roma Formation is gradational. Apparently both were laid down during the same marine incursion, and the possibility of the existence of some facies equivalents has already been discussed. In the area north of Wallumbilla the Formation is overlain by Tertiary lateritised sandstones, and on the Grafton Range by Tertiary basalt.

Marine fossils occur sporadically throughout the uppermost sediments of the Formation (Minmi Member), but some localities are extremely rich. Collections from 38 separate localities have been studied and determinations are tabulated (Table 3). Many of the forms are in need of taxonomic revision, but generally, published names are adhered to in this table. Faunal resemblances are with the Aptian Roma Formation, and the marine part of the Blythesdale Formation is tentatively assigned an Aptian age. Noteworthy species at present restricted to the Blythesdale Formation include *"Pseudomonotis"* sp., *Pseudavicula* sp. (=*Coilotis lens* of Whitehouse 1927), *Tancredia* sp. nov., ?*Solemya* sp., and *"Nerita"* sp. nov. Of particular interest is the occurrence of the species designated *"Pseudomonotis"* sp., which is represented by a single specimen. The form is very similar to that figured by Whitehouse (1946) as *Pseudomonotis* sp., from Neocomian sediments near Stanwell.

In the freshwater sediments, fossils occur infrequently and few of the localities are rich. As a consequence, collections are smaller and probably less representative than the marine ones. Even so, they are more comprehensive than any studied previously. Walkom (1915) recorded and figured *Equisetites rotiferum*? Tenison-Woods from Portion 443v, Parish of Wallumbilla; and Whitehouse (1927) listed *Taeniopteris spatulata* McClelland from "14 mile railway, near Yingerbay", and *Elatocladus plana* (Feistmantel) from the summit of Taylor Scarp (Portion 228, Parish of Bungeworgorai).

Table 3

OCCURRENCE OF MARINE FOSSILS IN THE BLYTHESDALE AND ROMA FORMATIONS IN THE ROMA-WALLUMBILLA AREA

r – rare (1-2) c – common (3-10) a – abundant (11–) o – observed but not collected ? – doubtful specific determination

Localities are roughly in stratigraphic order and are marked on the accompanying map.

| | BLYTHESDALE FORMATION | | |

TABLE 4

OCCURRENCE OF NON-MARINE FOSSILS IN THE ORALLO AND BLYTHESDALE FORMATIONS IN THE ROMA-WALLUMBILLA AREA

Localities are roughly in stratigraphic order and are marked on the accompanying map.

	ORALLO FORM.ⁿ		BLYTHESDALE FORMATION																																		
	L137	RD 88 L 50	L 49	L133	L129	L130	RD249	L114	L125	L131	L126	L127	L128	L111	L112	L113	L135	RD272	RD 67	RD273	L120	L121	L122	L123	L124	L118	L119	L115	L138	RD220	L109	L132	L136	RD130	RD131	L134
Podozamites sp.	×	×																																			
Halleophyllum crassum (Halle)		×																																		
Cladophlebis australis (Morris)	×	×		×									×								×	×															
Ginkgoites digitata (Brongniart)	×																							×													
Ginkgoites cf. *phillipsi* (Nathorst)																					×																
Taeniopteris spatulata McClelland	×		×	×		×	×	×	×	×			×			×	×	×		×	×	×	×			×	×	×			×	×					
Elatocladus plana (Feistmantel)	×	×	×							×			×		×					×	×	×						×			×						×
Equisetites sp. (cf. *E. rajmahalensis* of Walkom, 1915)		×								×							×									×										
Equisetites sp.							×														×	×						×			×						
Pterophyllum fissum Feistmantel	×		×																							×										
Ptilophyllum pecten (Phillips)																					×	×				×	×						×				
Brachyphyllum sp. (cf. *B. crassum* of Walkom, 1919)			×																									×								
Sphenopteris sp. (aff. *S. ampla* McCoy)			×																		×					×	×	×			×					
Sphenopteris flabellifolia (Tenison-Woods)																										×										
Araucarites cutchensis Feistmantel			×																												×					
Strobilites cf. *pascoei* Sahni																					×					×	×	×			×					
Microphyllopteris subtenera (Shirley)									×																												
Phyllopteroides feistmanteli (Eth. Jnr.)			×				×						×													×	×	×			×					
Phyllopteroides lanceolata (Walkom)										×											×																
Benstedtia sp.																	×					×									×					
Stenopteris laxum (Tenison-Woods)																															×					
Protovirgus sp.															×	×												×								
Unionid gen. & sp. nov.					×						×	×		×	×	×	×												×	×	×					
Worm trails and burrows																			×														×	×		
Coprolites																			×														×	×		

The flora comprises 18 species. Much of the material is fragmental and sporadic in its distribution (Table 4). In Jurassic and Lower Cretaceous sediments it is difficult to assess the age on purely palaeobotanical evidence, as many of the form species of plants are long-ranging, and in some cases such evidence seems to be at variance with that of other groups. However, a comparison has been made with large collections housed in the Geological Survey of Queensland from the Injune Creek Beds at Bymount and from the Stanwell Coal Measures, and this has yielded results which may be useful in correlation.

Apart from the long-ranging species *Taeniopteris spatulata* McClelland, *Elatocladus plana* (Feistmantel), *Cladophlebis australis* (Morris), and *Ptilophyllum pecten* (Phillips), only *Microphyllopteris subtenera* (originally described from Stanwell by Shirley (1898), as *Pecopteris subtenera*) occurs in both the Jurassic Injune Creek Beds and the Blythesdale Formation.

Affinities with the flora of the Stanwell Coal Measures of Upper Jurassic-Neocomian age are much closer. Typical Stanwell forms, *Phyllopteroides feistmanteli* (Eth. fil.), *Equisetites* sp. (cf. *E. rajmahalensis* of Walkom, 1915) and *Sphenopteris* sp. (a species similar to *S. ampla* McCoy and distinct from those of Burrum Coal Measures), are also common in the Blythesdale, as well as the narrow elongate variety of *Taeniopteris spatulata* described from Stanwell by Shirley (1902) as *Oleandridium jaculi*. For this reason the Blythesdale flora is thought to be of similar age. There are no close affinities with the flora of the Burrum Coal Measures of probable Albian age, although the occasional occurrence of the Burrum species *Stenopteris laxum* (Tenison-Woods), *Phyllopteroides lanceolata* (Walkom) and *Sphenopteris flabellifolia* (Tenison-Woods) may suggest that the freshwater Blythesdale sediments are slightly younger than those of the Stanwell Coal Measures.

Two species of freshwater pelecypods, *Protovirgus* sp. and a species which is apparently representative of a new unionid genus, have also been recorded, but they are of no use for age determination.

On the evidence available it is not possible to locate the Jurassic-Cretaceous boundary, and the base of the Blythesdale Formation is arbitrarily taken as the base of the Cretaceous in this area of sedimentation.

Whitehouse (1955) considered the age of the "Mooga Sandstone" and "Transition Beds" of Reeves

(1947) to be Lower Cretaceous. The most recent published statement on the age of these sediments is as follows:—"Recent palaeontological evidence, especially from microfloral studies, has shown that the Transition "beds" of the Blythesdale Group are Cretaceous and the remaining units of the Group are Jurassic; . . . ". (Bureau of Mineral Resources, 1961.)

Having regard to the thickness (500-550 ft.) and the stratigraphic position of the unit, as well as the palaeontological evidence, a Neocomian-Aptian age is suggested for the Blythesdale Formation.

In the Great Artesian Basin arenaceous sediments with marine horizons, conformably underlying the Roma Formation and its equivalents, are widespread These include the Longsight Sandstone of the north-western margin of the Eromanga Sub-basin, and the Gilbert River Formation and Wrotham Park Sandstone of the eastern margin of the Carpentaria Sub-basin. Preliminary determinations of their fauna by Hill (1960) (Longsight Sandstone), Dickins (1960) (Longsight Sandstone and Gilbert River Formation), and Woods (1961) (Wrotham Park Sandstone) suggest that they may be time equivalents of the Blythesdale Formation. In the Laura Basin marine sandstones from which Neocomian ammonites have been described (Woods, 1962) may also be Blythesdale equivalents.

Roma Formation

The history of this unit is given in Smith *et al* (1958). Whitehouse (1955) designated its type area as ". . . the banks of Bungeworgorai Creek just north and south of the railway line". This locality lies about 2 miles south of outcrops in which sandstones near the top of the underlying Blythesdale Formation are exposed, and, as the regional dip is about 1° south, the sediments of the type area are considered to be about 150-180 ft. stratigraphically above the base of the Formation.

The outcrop area has a characteristic "rolling downs" topography and is mostly grassland with few trees. However, in the eastern part of the area mapped, where the Formation is masked by a veneer of Quarternary residual sand and gravel, the "rolling downs" appearance is often lost and a dense vegetation of brigalow and belah is developed.

Thickness and Lithology

Owing to very low dips, repetition of lithologies, numerous small faults which displace the beds, and paucity and discontinuity of exposure, it is not possible to measure a section. In Clerk, Bungeworgorai, and Wallumbilla Creeks there are outcrops over a quarter of a mile long, but only limited thicknesses (30-40 ft.) are exposed. Two creek bank sections of 35 ft. measured in the type area are given by Allen (1961). Reeves (1947) estimated the thickness of the "Roma Series" (= Roma Formation plus the Minmi Member) in this area as exceeding 200 ft. The thickness of the Formation is now estimated as 200 ft.

Calcareous concretions in the Roma Formation in Clerk Creek at m.r. 148696. The concretions are in sandy beds.

Small normal faults are common, especially in the type area, where throws may be as large as 30 ft., although the majority are much smaller. Apart from those areas disturbed by faulting, the strata have been observed to undulate in many exposures, and these are interpreted as soft sediment settlement structures.

The outcropping sediments are rather monotonous interbeds of black gypseous shales and khaki-brown (weathered) and greenish (fresh) very fine-grained glauconitic silty sandstones, with minor black silty to sandy limestones and interlaminated shales and silty sandstones. The bulk of the sediments are shales. Those very near the base of the Formation occasionally have small lenses of subangular, medium-grained quartz sand, ½-1 in. in thickness. The upper part of the Formation is more silty and sandy than the basal part.

In A.A.O. No. 1 (Roma) well similar sediments have been observed in core 2 (101-105 ft.) and core 3 (150-170 ft.), and in both this well, as reported by Mott (1960), and the Hospital Hill wells the Formation is probably represented in the interval from 0-190 ft. Sediments similar to those outcropping have been observed to a depth of 189 ft. in cores from Builders Ltd. Roma No. 1 Scout bore.

Calcareous concretions are extremely numerous in both the shales and sandstones, and septaria occur occasionally. Those in the shales are in the main spherical and range up to 3 ft. in diameter in the exposure in Wallumbilla Creek, 5 miles south-east of Wallumbilla (m.r. 207692), but only rarely do they contain fossils. It is not clear whether all the concretions are epigenetic. In Bungeworgorai Creek about a quarter of a mile west of Mt. Abundance Homestead (m.r. 150695), and in Clerk Creek about 600 yds. west of its junction with Bungeworgorai Creek (m.r. 148696), there are thin conglomerates with concretionary calcilutite pebbles and rolled belemnite guards. The concretionary pebbles are often irregular in form and their origin here could be syngenetic. In the sandstone the concretions are of the bedding-plane type and represent areas of cementation of the more porous sediment by calcite. Various stages of cementation, from isolated ellipsoidal concretions, through strings of closely spaced ones which occasionally coalesce, to

the stage where the whole bed is cemented over a limited area, have been observed in the outcrops in Clerk Creek near its junction with Bungeworgorai Creek. These are almost certainly epigenetic and no doubt ground-water played a major role in their formation. Cone-in-cone limestone is also common.

In thin section the silty sandstones show 30-40 per cent. glauconite and this accounts for their greenish unweathered appearance. Highly angular quartz makes up the rest of the clastic fraction, and 10-15 per cent. of this shows strain extinction. About 20 per cent. of the rock is fine argillaceous matrix and the rocks have low permeability.

Mechanical analyses show that these very fine-grained silty sandstones are well sorted, with sorting coefficients (So.) 1·18-1·50. They differ from the marine Blythesdale sandstones in their smaller grain size and greater matrix content.

Environment of Deposition

Deposition in moderately quiet water is indicated by the fine grain size, thin bedding, and cross laminations of these sediments. Evidence of bottom disturbance can be seen in the intimate intermingling of silt and shale laminae and fragments, suggesting deposition in the zone of intermittent wave action. The presence of fossil wood and the frequent occurrence of marine fossils, thought to have been accumulated by gentle currents, in depressions, now seen as bulges in the under surface on the sandstone beds, also support a shallow water origin.

The abundance of glauconite suggests slow sedimentation in quiet, comparatively warm, shallow water, under anaerobic conditions.

The black shales derive their colour from finely disseminated carbonaceous matter. Such humic sediments indicate reducing conditions, usually due to restricted bottom circulation (Twenhofel, 1939).

Age and Stratigraphic Relationships

The Roma Formation conformably succeeds the Blythesdale Formation, the succession being gradational. In the south-eastern corner of the area mapped it is unconformably overlain by Tertiary lateritised sandstones, mottled upper Cainozoic sands, and a veneer of Quaternary residual sand and gravel and piedmont-type debris shed from the Tertiary lateritised sandstones. The residual Tertiary gravel and sand of Timbury Ridge, and the Tertiary basalts of Mt. Bassett also overlie the Formation unconformably.

Exposure of Roma Formation shale in Wallumbilla Creek, 5 miles south-east of Wallumbilla (m.r. 207692). This locality is believed to be the one from which most of the "Wollumbilla" fossils described by Charles Moore in 1870, were collected.

—Photo. J. T. Woods.

Purisiphonia clarkei, a sponge typical of a *Purisiphonia* horizon within the Roma Formation.

Marine fossils are sporadically distributed throughout the area of outcrop. Collections from 28 localities, some of them very rich, have been studied and determinations are tabulated (Table 4). The detailed distribution of the fossils is rather puzzling; they are frequently abundant in only one bed of an exposure, while adjacent lithologically identical beds are quite barren.

The available evidence suggests that there are two faunal horizons represented—a *Purisiphonia* horizon, which occurs about 60 ft. stratigraphically above the base of the Formation, and a horizon with abundant *Cyrenopsis,* which is 60-90 ft. stratigraphically higher. These horizons have been traced in scattered outcrops from Wallumbilla Creek as far as the junction of Bungeworgorai and Clerk Creeks, a distance of about 32 miles. For the most part they strike east-west, although variations in topography often produce considerable changes in the outcrop pattern, as the regional dip is low (about 1° south). This is especially so in the case of the *Purisiphonia* horizon. Nearly all of its exposures adjacent to the Western Railway are at elevations about 1,000 ft. above sea level, while those 3 miles to the north, in the area immediately south of Mt. Bassett, are topographically 200 ft. higher. South of Wallumbilla there is a considerable change in strike which is not expressed in the topography. The outcrop here parallels the south-easterly course of the creek and extends 2 miles further south than the regional dip would indicate.

The *Purisiphonia* horizon is characterized by the presence of *Purisiphonia clarkei* Bowerbank, abundant *Pseudavicula anomala* (Moore), *Maccoyella barklyi* (Moore), *"Astarte" wollumbillaensis* (Moore) and

occasional terebratuloid and rhynchonelloid brachiopods. There is a close relationship with the marine fauna of the Blythesdale Formation, and about half of its species are common to both. A study of the fossil collections with reference to the very detailed, plane-tabled, contour map of the area immediately south of Mt. Bassett, made by Roma Blocks Oil Co. N.L. (1938), has shown that the *Purisiphonia* horizon occurs there 60-80 ft. topographically above the top of the Blythesdale Formation. As these sediments are nearly horizontal, this closely approximates to the stratigraphic interval.

The stratigraphically higher fauna occurs in the sediments of the type area and is characterized by an abundance of *Cyrenopsis* cf. *C. meeki* Eth. fil. and the appearance of new forms. *Tatella* ? sp. is apparently replaced by *T.* ? *aptiana* Whitehouse and *Peratobelus australis* (Phillips) by *P. oxys* (Tenison-Woods), while *Australiceras* cf. *A. irregulare* (Tenison-Woods), *Toxoceratoides ?* sp., *Maccoyella rostrata* Eth. fil., *M. reflecta* (Moore), and *M. aff. M. corbiensis* (Moore) make their first appearance. *Pseudavicula anomala* (Moore), *Tatella maranoana* Eth. fil., *"Myacites" planus* (Moore) and *Purisiphonia clarkei* (Bowerbank) are apparently absent.

Woods (1961) recognized two Aptian faunas in the Blackdown Formation of the Wrotham Park area. These have been compared with the faunas of the Roma Formation. Considering that Wrotham Park and Roma are about 800 miles and 10° of latitude apart, the correlation of the faunas is surprisingly close. Species prominent in the early faunal horizon of the Roma Formation, notably *Pseudavicula anomala* (Moore), *Tatella maranoana* Eth. fil., *Tatella* ? sp., *Maccoyella barklyi* (Moore), *"Myacites" planus,* and *"Astarte" wollumbillaensis* (Moore) closely resemble forms prominent in the early Blackdown Formation horizons. In addition the early Blackdown Formation species, *"Actaeon" hochstetteri* (Moore) and *Thracia wilsoni* (Moore) occur in the Blythesdale Formation. As the later horizon of the Blackdown Formation is mainly characterized by ammonite species, close comparison with the younger Roma Formation horizon is not possible. However, *Peratobelus selheimi* (Tenison-Woods) occurs in both, and *Australiceras irregulare* (Tenison-Woods) and *Toxoceratoides* ? sp. nov. may be represented in the Roma Formation horizon by their analogues *Australiceras* cf. *A. irregulare* and *Toxoceratoides ?* sp. The abundance of ammonites in the Blackdown Formation is in strong contrast to their rarity in the Roma Formation.

The correlation of the fauna of the Roma Formation with that of the Blackdown Formation in the Wrotham Park area has an important bearing on the age of the Roma Formation, for, of the ammonites on which Whitehouse (1926a) based the Aptian age of his "Roma Series", only one came from the Roma area, most being from the "Walsh River" (Wrotham Park area). The sole specimen from Roma was referred to *Tropaeum arcticum* (Stolley), Etheridge Jnr. having previously figured it as *Crioceras jackii* (1909, pl. 32, fig. 2; pl. 34, fig. 1). To date this is the only specimen from the Roma area which has been figured. Other published records of ammonites from this area are by Whitehouse, who recorded (1926b) *Ancyloceras* from 2 miles north of Wallumbilla, and later (1927) recorded *Tropaeum* sp. nov. from Roma Downs Homestead (Portion 4, Parish of Tingun) and *Toxoceratoides* ? sp. from Portion 454, Parish of Hodgson. Of these, only the specimen identified as *Toxoceratoides* ? sp. has been located. To these records *Australiceras* cf. *A. irregulare* is now added. According to Casey (1960), *Australiceras* and *Tropaeum* are characteristic Aptian genera. Their occurrence in the meagre ammonite collections from the Roma area indicates a general Aptian age for the Roma Formation. *Toxoceratoides* is also an Aptian genus (Casey, 1961), but it is doubtful whether the specimens designated *Toxoceratoides* ? sp. are representatives of this genus. Further collection of ammonites will be necessary before a more refined age can be assigned to the Formation. The pelecypod fauna is not as useful as the ammonite fauna for overseas correlation and reference to the standard European stages. But, as the pelecypods are associated with an abundant Aptian ammonite fauna in the Wrotham Park area, their occurrence at Roma is interpreted as confirmatory evidence for the Aptian age of the Roma Formation.

The subdivision of the "Roma Series" into four faunal stages: Ancyloceratan Stage, Australiceratan Stage, Tropaeuman Stage, and Ammonitoceratan Stage, by Whitehouse (1928) was based on the evidence of the ammonite fauna, and on the development of tertiary and quaternary ribbing in *Maccoyella barklyi* and *M. corbiensis,* which he attributed to mutations. Woods (1961), who studied the ammonite faunas of the Wrotham Park area, failed to find support for this subdivision. The present study has shown that in *M. barklyi* at least, the development of tertiary and quaternary ribs is a function of increasing age and size and not a mutant condition. Examination of numerous specimens of this species has shown that until a height of 20 mm. is attained, the ornament of the left valve consists of 9 to 12 primary ribs with only secondary ribs intercalated in the interspaces. At this size tertiary ribs usually appear. These are confined to the centre of the valve at first, and develop irregularly in the anterior and posterior interspaces as the size increases. Quaternary ribs are rarely developed before a height of 40 mm. is attained. Specimens of *Maccoyella barklyi* with quaternary ribbing have been found in the earliest marine sediments of the area. In the case of *Maccoyella corbiensis* there is insufficient well preserved material available for any conclusion to be reached.

Whitehouse (1927) had attempted to apply his faunal stages to the sediments of the Roma area. He thought the absence of *Ancyloceras* from the early sediments of this area, coupled with the presence of tertiary ribbed *Maccoyella barklyi,* indicated overlap of the higher stages. This has not been confirmed by the present study; rather, the sequence is reasonably complete.

Equivalents of the Roma Formation are apparently widespread in the Great Artesian Basin, as Hill (1960) recorded a "Roma fauna" from the lower part of the Wilgunya Formation of the Eromanga Sub-basin, and Woods (1961), as discussed previously, has identified a similar fauna from the Blackdown Formation of the Carpentaria Sub-basin.

CAINOZOIC STRATIGRAPHY

Tertiary Lateritised Sandstones

The oldest Cainozoic sediments of the area outcrop north of Wallumbilla, where their representatives form buttes which rise as high as 200 ft. above the general elevation. East of the map area, around Yuleba, they are more extensively developed and largely cover the Mesozoic sediments. However, at two localities, Cox's Hill, 12 miles north of Wallumbilla (m.r. 199717), and a small butte at m.r. 199712, the elevated lateritised sediments are interpreted as altered representatives of the Blythesdale Formation. There they may represent highs in the Tertiary depositional surface, or their position may have been structurally controlled, as sediments at the base of the butte at m.r. 199712 locally dip 40°W., and some at the top of Cox's Hill are apparently vertical.

As there has been considerable erosion it is not possible to estimate the total thickness of these sediments. In a butte, 6 miles north of Wallumbilla (m.r. 203708), there are at least 150 ft. preserved, while on the Great Divide, in the watershed between Appletree, Yuleba, Sugarloaf, and Barton Creeks, only about 50 ft. remain. The latter were mapped as part of the "Desert Sandstone" by Jack and Maitland (1895), although in the area studied, the unit mapped by them as "Desert Sandstone" is generally the Gubberamunda Sandstone.

The lithology is dominantly fine- to medium-grained, rather clayey and feldspathic sandstone, with coarse-grained and conglomeratic lenses, shale partings, and, in some places, abundant shale fragments. Lenses of clayey and silty shales also occur. Some of the sandstones contain isolated, apparently water-worn pebbles and cobbles of billy, while at m.r. 204721 and m.r. 205732 small impersistent lenses of conglomerate with billy occur. In some places the sediments closely resemble the underlying Mesozoics.

These sediments have been lateritised and are extensively mottled. In the cappings of the buttes the ferruginous zone has been eroded, frequently leaving a pisolitic ironstone gravel ("buckshot gravel") strewn over the surface. Local silicification has been observed in some instances, but there is no sheet of billy or duricrust preserved in the area mapped. Silicification is often quite selective and concentrated around centres, resulting in rounded nodules of "sub-billy". Beds of these have a superficial appearance of conglomerate, but the boundaries between "pebbles" and matrix are not sharp. This feature distinguishes them from the conglomerates with billy pebbles at m.r. 204721 and m.r. 205732. The incipient silicification is often accompanied by brecciation and the development of columnar joints.

It is believed that these buttes represent remnants of a dissected surface, which was base-levelled and lateritised in Tertiary time, then subsequently elevated prior to dissection. The remnant surface now slopes southwards.

The Tertiary sediments were discussed by Whitehouse (1940, p.57), who suggested they might be equivalent to his Glendower "Series". That the two have much in common was confirmed during a recent examination of the Glendower Formation in its type area at Glendower. Both have similar topographic expression (buttes and mesas rising well above the surrounding country); both have similar lithologies (sandstones, shales, and conglomerates), although the Glendower has more conglomerate; both contain billy pebbles and cobbles; and both are lateritised.

The occurrence, within the lateritised Glendower sediments, of water-worn pebbles of billy, the development of which was attributed to an earlier lateritic process, led Whitehouse (1940) to conclude that the Formation post-dated the main period of lateritisation of the early Pliocene, but predated a second but milder period of lateritisation of the late Pliocene. On the other hand, Twidale (1956, p.873) considered the Glendower sediments as pre-Miocene (?) and claimed that they contributed to his early to middle Tertiary surface of erosion. Even allowing for the acceleration of erosion during pluvial phases and by uplift, it appears unlikely that the extensive dissection of the Glendower sediments could have been accomplished in post-Pliocene time. The origin of the billy pebbles constitutes a separate problem. Reports by Jessup (1960) and by Paten (1961) of occurrences of post-lateritic billy, believed to have formed independently of lateritic processes, have cast some doubt on the direct genetic association of billy with lateritic profiles.

As with the Glendower Formation the physiographic evidence suggests that the Tertiary sediments of the buttes north of Wallumbilla are older than Pliocene. However, in the absence of fossils, very little definite evidence as to their age can be advanced. They are unconformable on sediments of the Gubberamunda Sandstone and the Orallo, Blythesdale, and Roma Formations and so are post-Lower Cretaceous. While the stratigraphic relationship of the basalts of the Grafton Range and the lateritised sediments cannot be directly established, the former are thought to be younger, since they are not themselves lateritised.

The Telgazli Formation of Jenkins (1959), which has its type area about 40 miles to the south, has a very similar physiographic expression and, apart from the fact that billy has not been reported, its lateritised sediments closely resemble those north of Wallumbilla.

The progressive erosion of the lateritised Tertiary sediments in the Wallumbilla area has contributed to reddish quartzose sands and billy gravels in residual, colluvial, and alluvial deposits ranging in age to the present time.

Tertiary Sands and Gravels

Weakly consolidated sands and gravels of probable Tertiary age cover the surface of Timbury Ridge, a south-westerly trending extension of the Grafton Range rising to about 150 ft. above the alluvium of Bungil Creek. It is cut by Bungil Creek into two portions, one north-east of Roma (the ridge proper) and the other south of Roma.

The sands are loose, reddish-coloured, medium- to coarse-grained, poorly sorted, and largely composed of iron-stained quartz grains. The associated gravels have abundant rounded pebbles of white quartz (0.25-0.5 in. in diameter) and larger well rounded billy pebbles and cobbles. Billy also occurs in large blocks up to 3 ft. in diameter. On Timbury Ridge, these deposits are only a few feet thick. In an unpublished map of Roma Blocks Oil Co. N.L. (1938) they are shown as a "coarse gritty sandstone" horizon and their thickness is given as 2 ft. The ill-sorted nature of the sediments, their lack of stratification in places, and the considerable disparity in the size ranges of the billy suggest the deposit here may be partly residual.

On the Grafton Range and Mt. Bassett the basalts appear to overlie gravels with cobbles of billy, although the exposure is poor owing to the scree of basalt debris on the slopes. This is also the relationship shown by Jensen (1926b, p.51, fig. 6), who interpreted the gravels as deposits of an old stream channel along which the basalts flowed. As pointed out by Jensen, there has been considerable post-basalt erosion, and the basalts and underlying gravels are both probably of Tertiary age. The basalts are topographically higher than the sands and gravels of Timbury Ridge and it is likely that the gravels of this ridge represent an extension of the sediments of Mt. Bassett and the Grafton Range.

Because of the absence of lateritic effects it is thought that the sands and gravels are younger than the laterised sediments north of Wallumbilla. Possibly the gravels were derived in part from their erosion, as were the very similar residual deposits further to the east.

The pre-basalt "boulder mounds" of Jensen (1926b), which occur north of Mitchell, are apparently equivalent, although in some cases, where their pre-basalt age cannot be demonstrated, they may be younger.

Mottled Sand

In Wallumbilla Creek on the western outskirts of the town of Wallumbilla (m.r. 202697) up to 6 ft. of mottled, weakly consolidated, fine- and medium-grained quartzose sand unconformably overlies shale of the Roma Formation. The junction is very irregular and the basal 9 in. of the sand is poorly sorted, very coarse and conglomeratic. Cobbles of mottled ferruginous sandstone with abundant shale fragments, apparently derived from the lateritised Tertiary sediments of the buttes to the north, occur in this basal part, together with fragments of the underlying shale and rounded pebbles of quartz, jasper, and billy. Similar sediments have been observed in Pickanjinnie Creek at Trafford Park homestead (m.r. 196692), but they are of limited areal extent and it is not possible to map them.

The sands are characterized by well developed mottling. Where they are thin the underlying Cretaceous shale is also affected, with the development of 0·5 to 2 in. maroon bands alternating with white leached bands of similar thickness.

These sediments are interpreted as channel deposits consisting of detritus eroded from the lateritised Tertiary land surface now represented by the buttes to the north. They predate the present drainage system and its high terraces. Their mottling could be advanced as evidence of a younger, less intensive period of lateritic action in this area.

Further to the east; in the valley of the Condamine River, mottled sands which predate the present drainage system have been referred to by Woods (1960) as the Chinchilla Sand. This Formation contains a vertebrate fauna to which Woods assigned a tentative

Mottled sand of probable Upper Tertiary age, unconformably overlying shale of the Roma Formation in Wallumbilla Creek, on the western outskirts of the town of Wallumbilla (m.r. 202697).

Pliocene age. Although no fossils have been found in the mottled sands at Wallumbilla the physiographic and lithological similarities of the two are such that they may be of similar age.

Tertiary Basalts

These are best developed on the Grafton Range where flow basalts are more than 150 ft. thick, while similar but thinner flows cap Mt. Bassett to the south In addition, there are a few small scattered basaltic intrusions. One of these, a small possible laccolith about 22 miles from Roma on the main Roma-Injune road, is at present being quarried. Dolerite dykes 20 ft. in width were reported in Appletree Creek by Jensen (1928). The basalts are both massive and vesicular, and are olivine-bearing. Denmead (1927) described samples from north Mt. Bassett (= Grafton Range) and from Portion 167v, Parish of Beaufort. As pointed out by Jensen (1926b) there has been considerable post-basalt erosion and the basalts are probably of Tertiary age.

Residual Sands and Gravels

Between Blythdale and Wallumbilla the Roma Formation is masked by a veneer of billy gravels and reddish quartzose sands which are thought to be largely residual in origin. They are well developed on the stream divide between Blyth and Pickanjinnie Creeks. It is considered that they are remnants of a Tertiary lateritised surface, which have been eroded, beyond the stage represented by buttes and mesas, to residual deposits of sand and gravel standing at a level well below that of the original surface.

The ubiquitous occurrence of billy gravel on minor stream divides might be explained in this way. Also some of the "boulder mounds" of Jensen (1926b) may be of this type.

These residual sediments sometimes resemble those of the high terraces of the present streams, no doubt reflecting their common provenance.

Sediments of the Present Drainage System

These include the sediments of high terraces, at present undergoing erosion, and alluvium which is still being deposited.

The terrace sediments are too limited in extent to be mapped as a separate unit, although they frequently form very prominent outcrops in creeks. Sections up to 30 ft. thick have been observed in Blyth, Bungil, Mooga Mooga, and Bungeworgorai Creeks. Usually their unconformable relationship can be recognized, but where this is not evident they can be readily distinguished from the Mesozoics by their less coherent nature and by the presence of billy. These sediments are generally unconsolidated, poorly sorted orange-red quartz sands and frequently they have conglomerate lenses with billy and detrital silicified fossil wood at their base. In Bungeworgorai Creek at m.r. 137724, terrace sediments, which form the upper part of the section there, display weak mottling in greys and reds beneath an ironstained zone 6 ft. in thickness.

Quaternary sediments of a high terrace of Bungeworgorai Creek, unconformably overlying sediments of the Orallo Formation at m.r. 137724.

Wide areas adjacent to the present streams are at present intermittently receiving sediments and these are shown on the map as Quaternary alluvium.

ECONOMIC SUMMARY

The search for oil in Queensland was initiated in the Roma area when in 1900 petroliferous gas was struck at 3,700 ft. in a second town water bore—Q.G. No. 2 (Hospital Hill)—and the area has been considered an important prospect ever since. At present the Roma area forms part of Authority to Prospect 55P, held by Associated Australian Oilfields No Liability, and is being actively explored geologically, geophysically, and by drilling.

To date 41 wells have been drilled. The early ones were drilled without geophysical services and adequate drilling techniques. Most reported shows of oil and gas; some on Hospital Hill obtained large gas flows, and A.R.O. Blythdale wells and R.B.O. No. 1 (Mt. Bassett) produced several hundred gallons of oil. Details of this early drilling are given by Geological Survey of Queensland (1960).

The results of the current exploration are encouraging (Traves and Thralls, 1960; Traves, 1962), and commercial natural gas fields may be proved within the area. Large flows of gas have been obtained from three wells—A.A.O. No. 4 (Hospital Hill), A.A.O. Timbury Hills No. 2, and A.A.O. Pickanjinnie No. 1. The first produced at the rate of 870,000 cubic feet per day through a $\frac{3}{8}$ in. choke, the second at 1,500,000 cubic feet per day through a $\frac{1}{4}$ in. choke, and the third at 6,500,000 cubic feet per day through a 1 in. choke. Prospects for commercial oil production have recently been enhanced by the discovery of oil in the Hospital Hill Sandstone in A.A.O. Richmond No. 1 well, 9 miles south-east of Roma. On test the productive section (4,005-4,018 ft.) yielded oil at the rate of 300 barrels per day and gas at 120,000 cubic feet per day. Previously this Sandstone was regarded only as a gas project.

Over the years attempts have been made to utilise the natural gas. The earliest of these was in 1906, when gas from Q.G. No. 2 (Hospital Hill) well, after blowing wild for five years, was used to illuminate the town. However, after ten days the gas flow failed. In 1928 an absorption plant was erected to recover the gasoline content of gas from R.O.C. No. 1 (Hospital Hill) well. The average recovery was 1·3 pints of gasoline per 1,000 cubic feet of gas, and from 1928 to 1932 about 30,000 gallons were sold directly from a pump as motor spirit. At present there are two wells producing natural gas in the area—A.A.O. No. 4 (Hospital Hill) and A.A.O. Timbury Hills No. 2. Since April 1961, fuel for the Roma town powerhouse has been supplied by them, and the supply shows every promise of continuation.

Pressure water is an important product in this area and the Gubberamunda Sandstone, sands of the Orallo Formation and, to a lesser extent, the Mooga Sandstone Member of the Blythesdale Formation yield plentiful artesian supplies from shallow depths. Big supplies are also available at greater depths from sands of the "Bundamba Group", which occur under Roma at about 2,700 ft.

Coal occurs in the Orallo Formation and has been reported on by Cameron (1913) and Jensen (1926b). However, there are no known seams of workable thickness.

Kerosene shale was reported from near Orallo by Jensen (1926b). On destructive distillation this yielded 44·8 gallons of oil per ton. The sediments of this locality form part of the Orallo Formation.

The clayey shale of the Roma Formation is suitable for brick-making (Allen, 1961), but has not been used for this purpose.

The gravels and sands of Timbury Ridge and the residual deposits between Blythdale and Pickanjinnie are widely used in road making, particularly in the black soil areas. The extensive basalt flows of Mt. Bassett and the Grafton Range are probably capable of similar exploitation. At present the only basalt quarried in the area is that of a small, apparently laccolithic intrusion, about 22 miles from Roma on the main Injune road.

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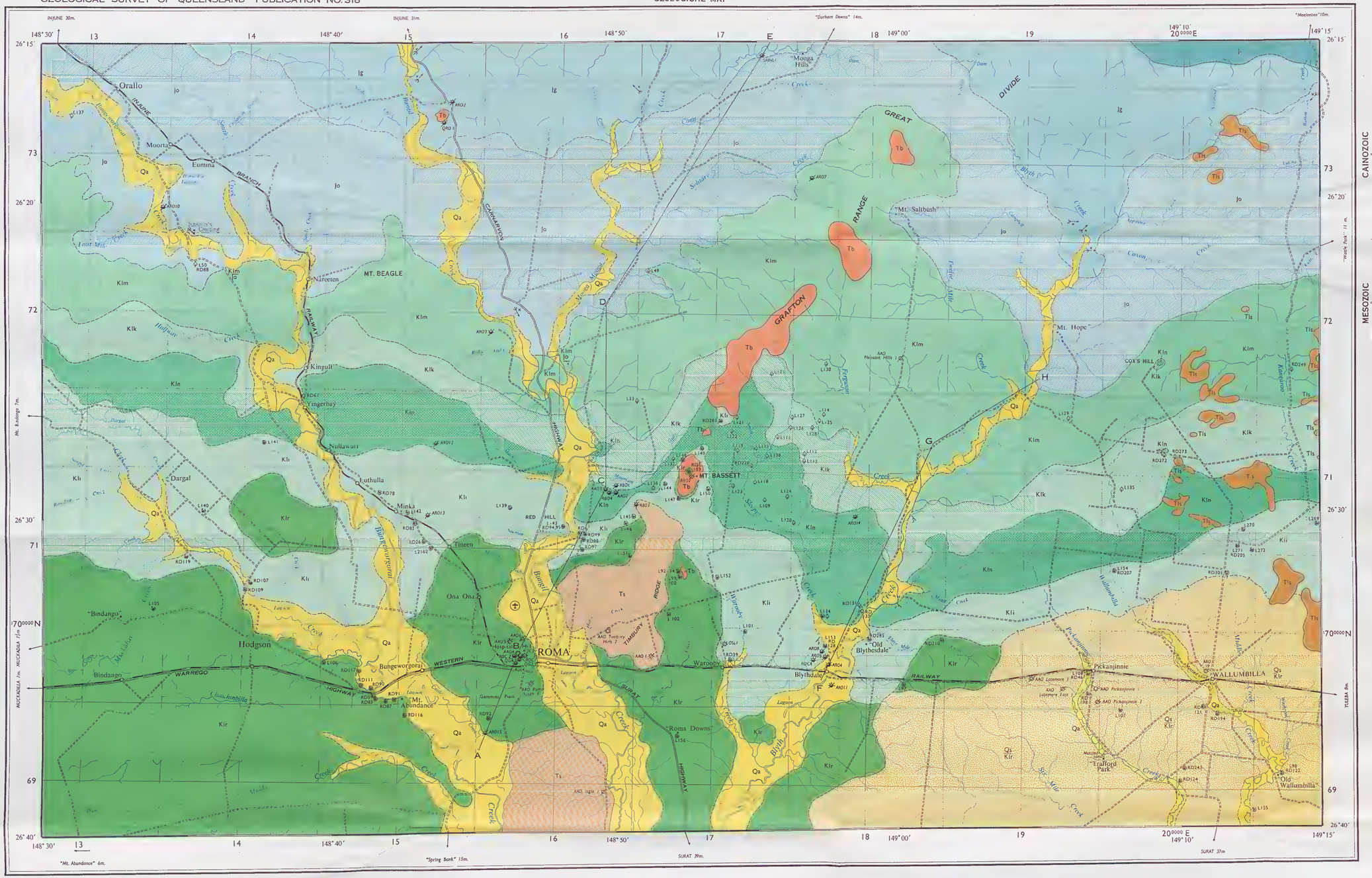
GEOLOGICAL SURVEY OF QUEENSLAND PUBLICATION NO. 318

ROMA – WALLUMBILLA AREA

GEOLOGICAL MAP

1:126,720 SPECIAL



Reference

CAINOZOIC	QUATERNARY	Qa	Alluvium
		Qs	Residual sand and gravel
	TERTIARY	Tb	Basalt flows and intrusives
		Ts	Sand and gravel
		Tls	Lateritised sandstone
MESOZOIC	LOWER CRETACEOUS – APTIAN	Roma Formation – Klr	Shale, fine grained glauconitic sandstone and limestone
	LOWER CRETACEOUS – NEOCOMIAN	Blythesdale Formation – Kli	Minmi Member: Calcareous glauconitic sandstone
		Blythesdale Formation – Kln	Nullawurt Sandstone Member: Fine to very fine quartz sandstone
		Blythesdale Formation – Klk	Kingull Member: Calcareous siltstone, shale and calcareous lithic sandstone
		Blythesdale Formation – Klm	Mooga Sandstone Member: Quartz and lithic sandstone siltstone and shale
	JURASSIC	Orallo Formation – Jo	Lithic sandstone, shale and conglomerate
		Gubberamunda Sandstone – Jg	Poorly cemented medium to coarse quartz sandstone
		"Injune Creek beds" – Ji	Siltstone, shale and calcareous lithic sandstone

- Geological boundary, position accurate
- Geological boundary, position approximate
- Geological boundary, position inferred
- Strike and dip of strata
- Direction of sediment transport determined by cross-stratification
- Marine fossil locality
- Non-marine fossil locality
- RD108 / L153 — Fossil locality reference number
- Railway Line
- Main road
- Secondary road
- Other roads and vehicle tracks
- "Mt. Hope" — Homestead
- Airfield

Oil wells:

- Dry hole (abandoned)
- Dry hole with show of gas (abandoned)
- Dry hole with show of oil and gas (abandoned)
- Gas well
- Gas well (abandoned)

Topographic base compiled by Drafting Section, Department of Mines, Queensland.
Slotted template assembly by courtesy of the Division of National Mapping, Department of the Interior, Canberra.
Photography 1:83,000 May 1962
Transverse Mercator Projection
Australian National Grid

SCALE 1:126,720

Miles 0 1 2 3 4 5 6 7 8 9 10

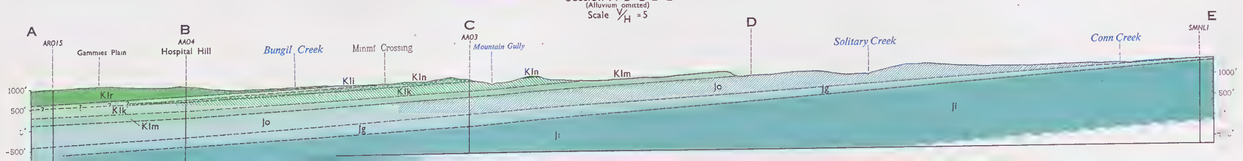
Yards 5000 0 5000 10000

KEY TO 1:250,000 SERIES

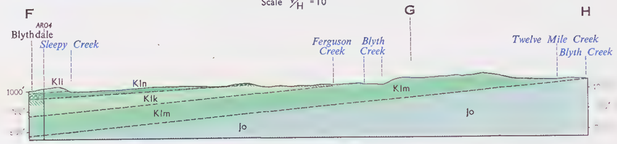
Geology by: R.W. Day B.Sc., Geologist
Drawn by: Drafting Section, Department of Mines, Queensland.

Geological mapping based on photo interpretation supplemented by numerous ground traverses

Section A-B-C-D-E
(Alluvium omitted)
Scale $\frac{V}{H}$ = 5



Section F-G-H
(Alluvium omitted)
Scale $\frac{V}{H}$ = 10



ROMA - WALLUMBILLA AREA
1:126,720 SPECIAL

Copies of this map may be obtained from the Geological Survey of Queensland, Brisbane

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QUEENSLAND
DEPARTMENT OF MINES

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GEOLOGICAL SURVEY OF QUEENSLAND
(A. K. Denmead, M.Sc., Chief Government Geologist)

PUBLICATION No. 319

THE TERTIARY GEOLOGY OF THE BOULIA REGION, WESTERN QUEENSLAND

BY R. J. PATEN, B.Sc.

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COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

Minister: SENATOR THE HON. SIR WILLIAM SPOONER, K.C.M.G., M.M.
Secretary: SIR HAROLD RAGGATT, C.B.E.

STATE OF QUEENSLAND

DEPARTMENT OF DEVELOPMENT AND MINES

Minister: THE HON. E. EVANS, M.L.A.
Under Secretary: E. K. HEALY.

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Director: J. M. RAYNER.

This Report was prepared in the offices of:

Bureau of Mineral Resources, Geological Branch: Chief Geologist, N. H. FISHER.

Geological Survey of Queensland: Chief Government Geologist, A. K. DENMEAD.

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SUMMARY

Large areas of Tertiary sediments confined to four tectonically controlled sedimentary basins occur partly within the Boulia, Glenormiston, Springvale, and Mount Whelan 1:250,000 Sheet areas in far western Queensland. Carbonate, argillaceous, and arenaceous sediments and siliceous sinters were deposited. Fossils occur throughout, but are rare except in one basin. One deposit has been lateritized, another silicified to billy, and the remainder partly silicified to chalcedony and common opal; all silicification post-dates the laterite.

INTRODUCTION

This report is based mainly on the author's mapping and observations as a member of the 1957-59 joint field parties of the Bureau of Mineral Resources and Geological Survey of Queensland, which mapped the Boulia, Glenormiston, Springvale, and Mount Whelan 1:250,000 Sheet areas in western Queensland (Fig. 1). Relevant parts of adjacent areas were briefly examined.

During the mapping project, extensive areas of superficial Tertiary sediments were mapped and their considerable extent beyond the area of operations established. Four main areas of Tertiary lacustrine deposition, one of which is of possible fluviatile origin, were recognised (Fig. 2):

1. Springvale Basin

2. Marion Basin (possibly fluviatile)

3. Austral Downs Basin

4. Noranside Basin

Scattered siliceous spring deposits also occur in the region. Argillaceous and carbonate sediments were laid down in the Springvale Basin, arenaceous sediments in the Marion Basin, and carbonates in the Austral Downs and Noranside Basins. Other small carbonate deposits occur in the Breadalbane and Toko Range areas. Small Tertiary basins also occur at Old Cork and elsewhere to the east of the Boulia region (W. Jauncey, pers. comm.).

Disscussions of the basins refer mainly to those parts within the area mapped; only the Noranside and Springvale Basins lie wholly within that area. The development of billy on the Marion Formation is discussed in detail.

SPRINGVALE BASIN

The Springvale Basin was a small isolated basin developed superficially within the Great Artesian Basin in the Springvale area about 80 miles south-east of Boulia.

Casey (1959), after a short reconnaissance traverse in the area, named the sediments within this basin the 'Springvale Formation' and described them briefly. The type area was given as 'in flat-topped hills two miles south-west of Springvale homestead', with a reference section 'in the hills south of Junction Yard, 16 miles south-south-east of the homestead'.

The lithologies described were 'red vuggy sinter over hard grey sinter containing biscuit-like vuggy spring nodules, over silicified fine sand', and elsewhere 'chert with ostracods and gastropods, dense siliceous (?) dolomite and greenish chert'. Later, more detailed, mapping has shown that two unconformable units are included in the 'Springvale Formation', and the sediments are now redefined as: (a) Springvale Formation, the older unit, typified by Casey's type locality, (Paten (1960) used the name in this sense) (b) Horse Creek Formation, the younger unit, to which Casey's reference section belongs.

Fig. 1

LOCALITY MAP

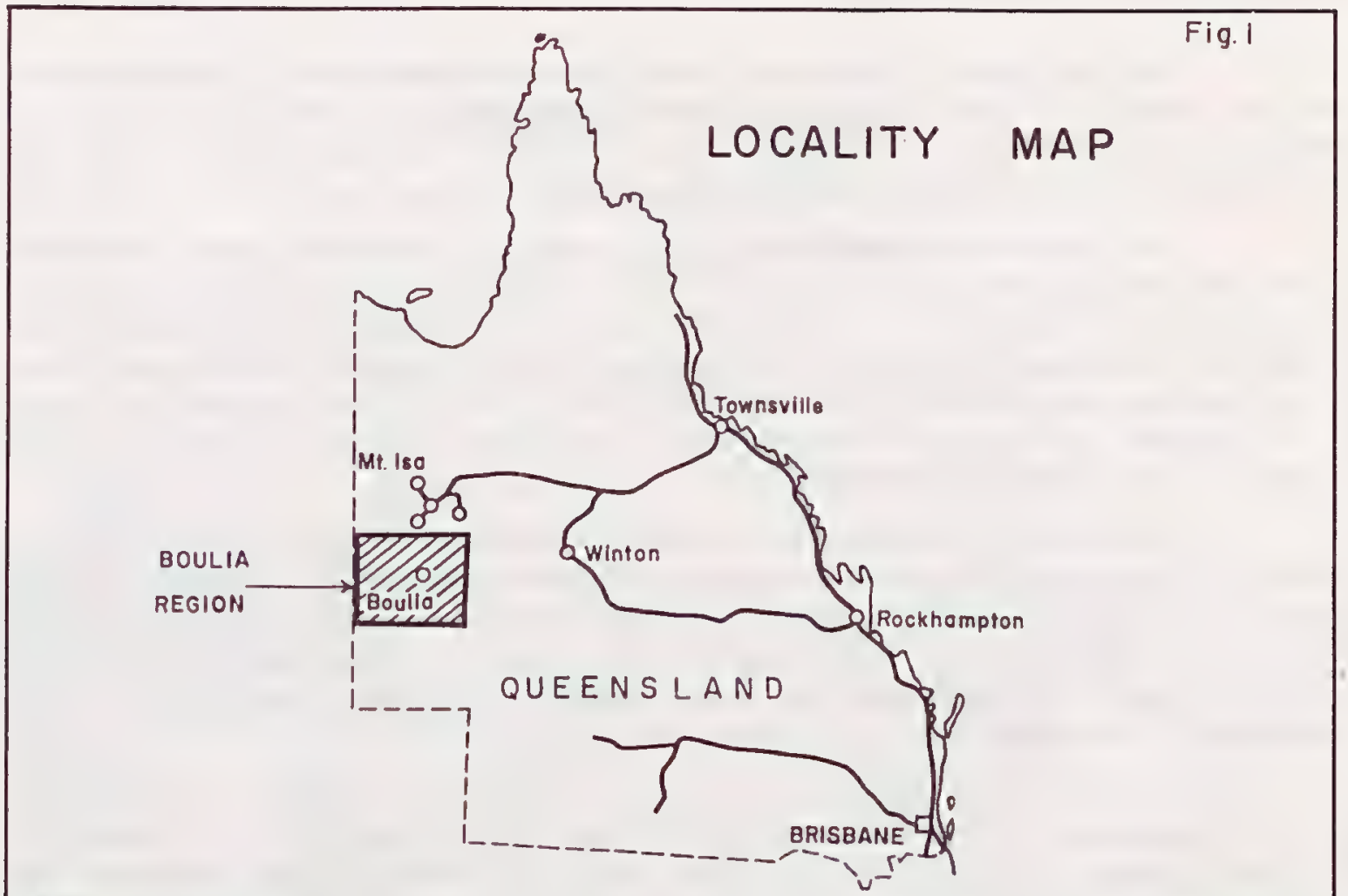
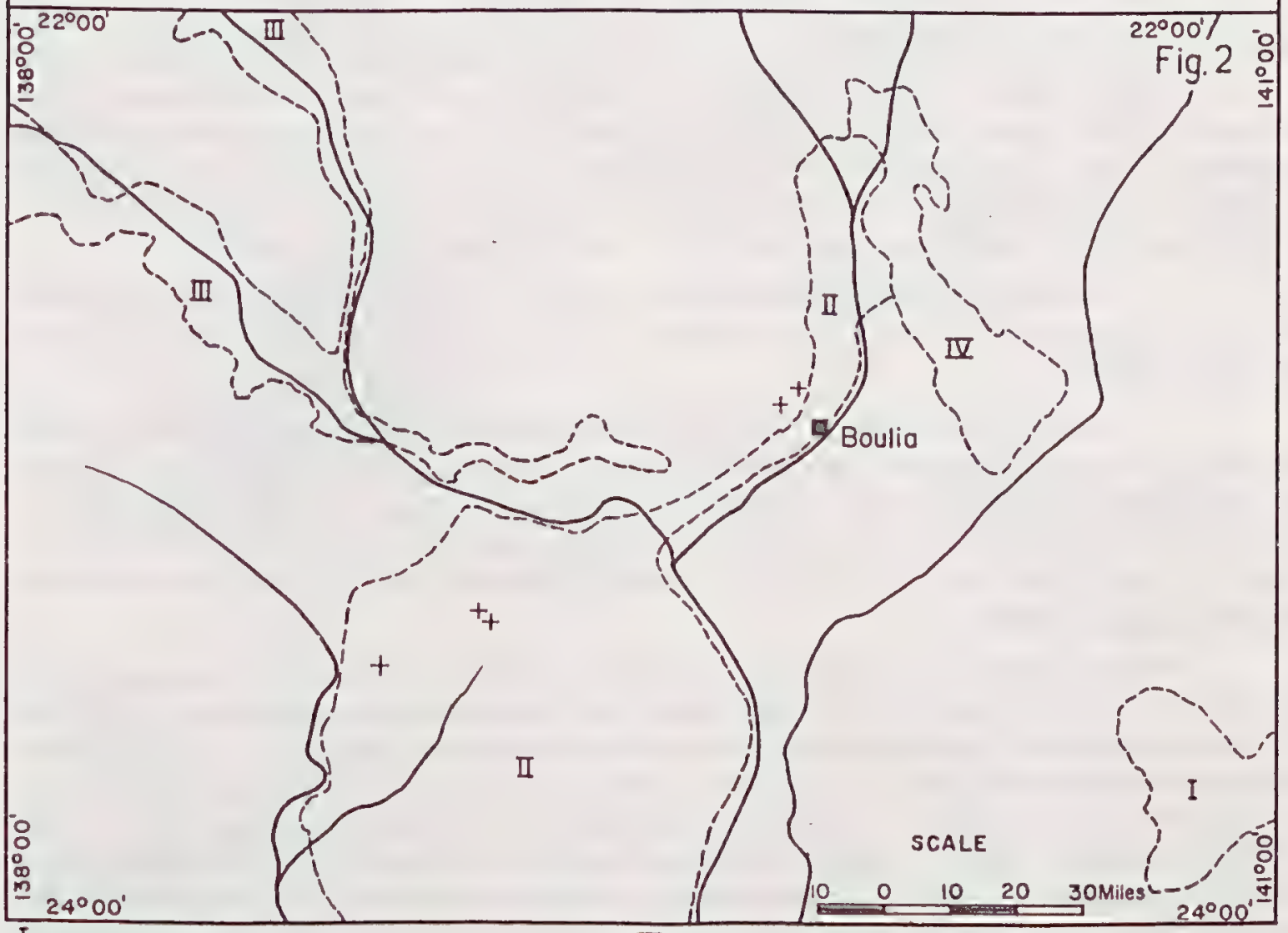


Fig. 2



I Springvale Basin
II Marion Basin
III Austral Downs Basin
IV Noranside Basin
\+ Siliceous Spring Focus

Springvale Formation (Paten, 1960)

The Springvale Formation is named after Springvale Station, a cattle property about 80 miles south-east of Boulia. Springvale Homestead is situated on the east bank of Spring Creek, a tributary of the Diamantina River, at Lat. 23° 33'S and Long. 140°42'E. The type area is in red flat-topped hills 2 miles south-west of the homestead (Pl. 1, Fig. 1).

The formation extends from 4 miles north of the homestead, south as scattered low hills for about 22 miles to Uka Tank, and from 3 miles west of the homestead east-south-east for about 27 miles to the Goyder Range on the western side of the Diamantina River. Throughout the Springvale Basin the post-Cretaceous rocks form a plateau which stands above the surrounding sand and soil plains developed on the underlying Artesian Basin sediments. The Springvale Formation is blanketed by the overlying Horse Creek Formation but is extensively exposed by dissection of the younger rocks (Figs. 3, 4, 5).

Lithologies represented are a suite of iron-stained siliceous rocks, limestone, swelling clay, and rare sandstone. The iron-stained siliceous rocks are the commonest and are fine-grained, harsh to the touch, dense and rarely porous. Owing to irregular mottling by iron oxide, they are characteristically brightly coloured, ranging from pinkish red to cream. The iron-stained siliceous rocks are best exposed on the eastern side of Spring Creek immediately to the south of Springvale Homestead.

In thin section these rocks display a uniform texture of clotted opaque silica with varying amounts of brownish iron-oxide staining. Sand grains are rare and commonly the grain margins are replaced by opaline silica. Silicified secondary (concretionary) textures may be preserved in the clotted matrix (Pl. 1, Fig 2). Rare remnant areas of crystalline calcite occur, and the clotted matrix in some sections has a texture suggestive of that of mosaic calcite. At S148, about 16 miles south-south-east of the homestead, these siliceous rocks grade into fine-grained grey limestone, and unaltered parent limestone crops out at S145 in the same area. It is fine-grained, grey, and crystalline, with small clots of fine lime carbonate, and is characterized by rosette and cruciform calcite recrystallization. Thin-shelled molluscan fragments occur in the limestone at this locality.

This siliceous suite is hence the product of chemical alteration of the predominantly limestone portion of the Springvale sequence, though some may be altered calcareous clay.

Grey algal limestone and limestone beds (Fig. 3), containing thin-shelled gastropods, crop out in the western part of the area underlain by the formation. Practically all this material is replaced by brownish and bluish silica ranging from lustrous translucent to dull opaque, so that the outcrops are in fact chert, consisting of a very fine micromosaic of quartz (Pettijohn, 1957, p.432). The silica commonly preserves the original clotted texture of the limestone.

Clay, with rare sandstone and limestone lenses, crops out in sequences up to 60 feet thick in the western part of the formation, but is not common east of Spring Creek. The clays are brownish, greenish, and grey in colour and disperse rapidly in water. The best exposure occurs at S151 in the type area (Pl. 1, Fig. 1) and similar clays occur in small hills on the east side of Gum Creek on the road from Springvale to Diamantina Lakes. Clays from the type area swelled to three times their volume when tested in water. Near S145 on the west side of Spring Creek, hard clay with a white efflorescence of magnesium chloride on weathered surfaces crops out. Analysis of this clay by the Queensland Government Chemical Laboratory gave (Analysis 1569/59 G.S.):

TERTIARY SEDIMENTS

SPRINGVALE

SHOWING LOCALITIES IN TEXT

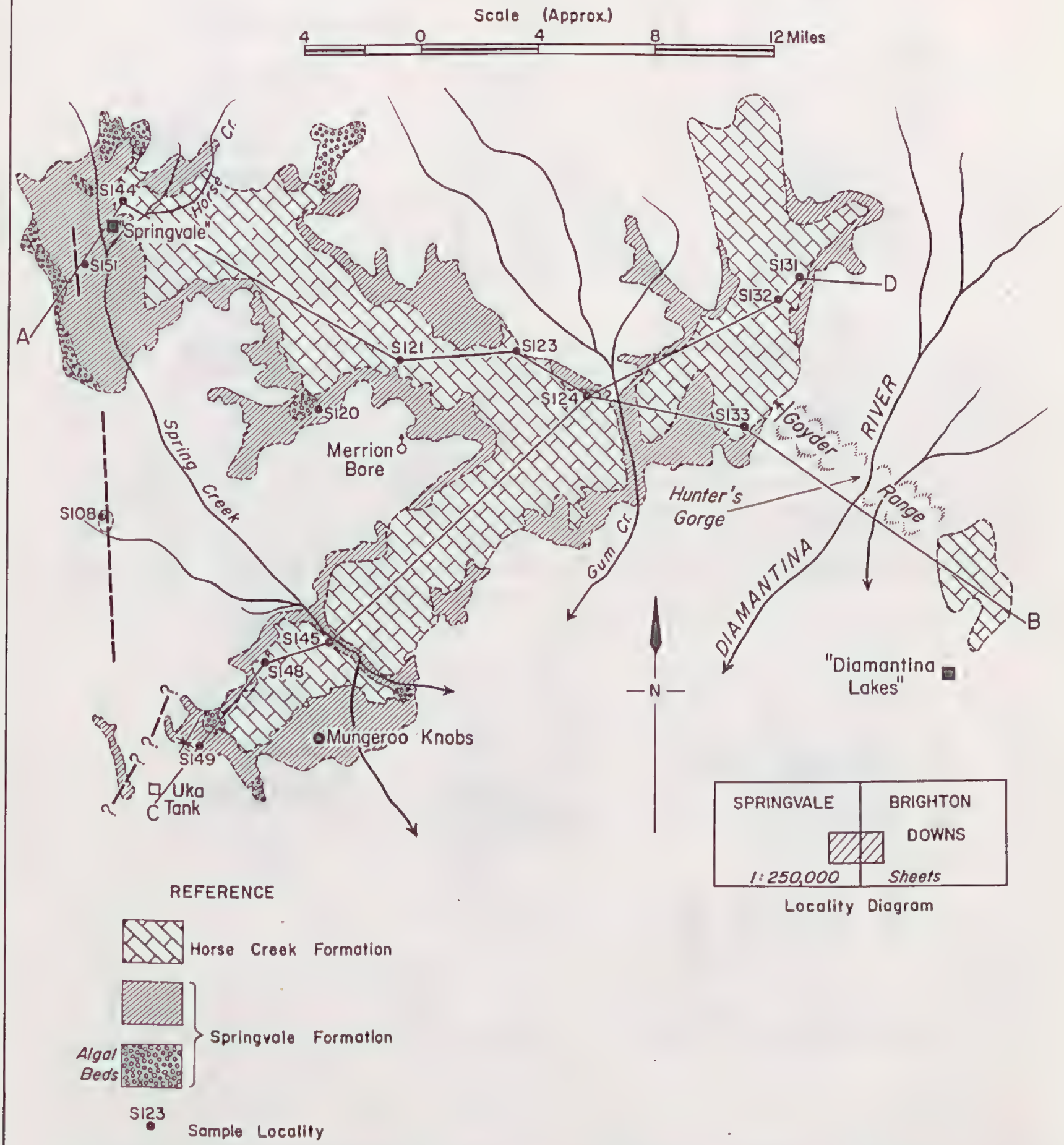


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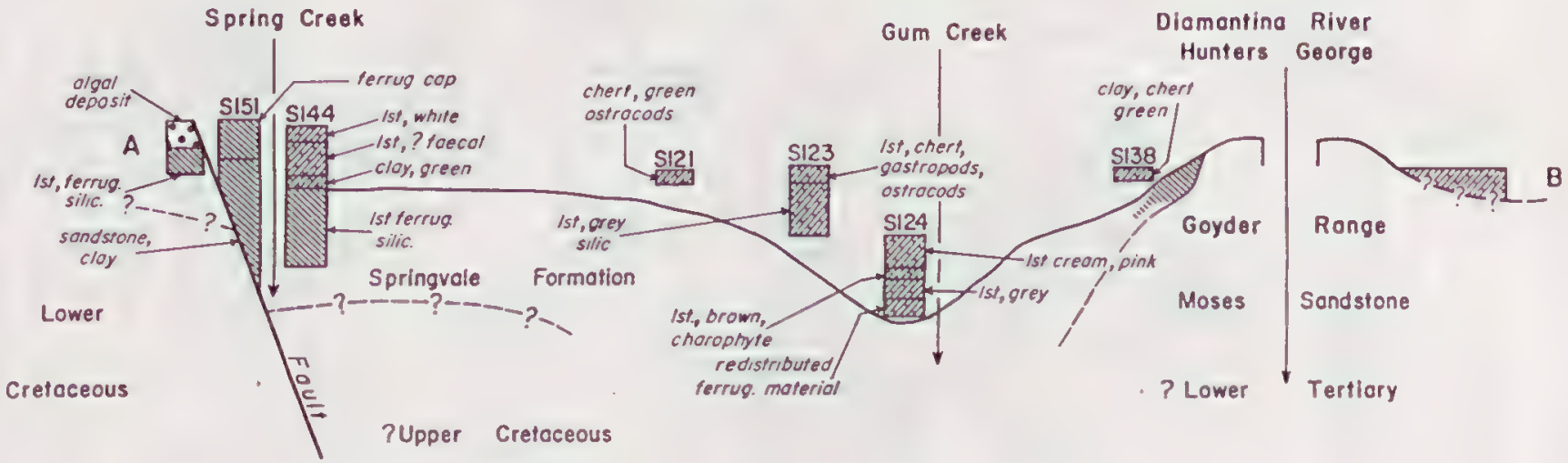
Fig.4

SECTION A-B



REFERENCE

Horse Creek Formation

Springvale Formation

Algal Beds

SCALE

Horizontal

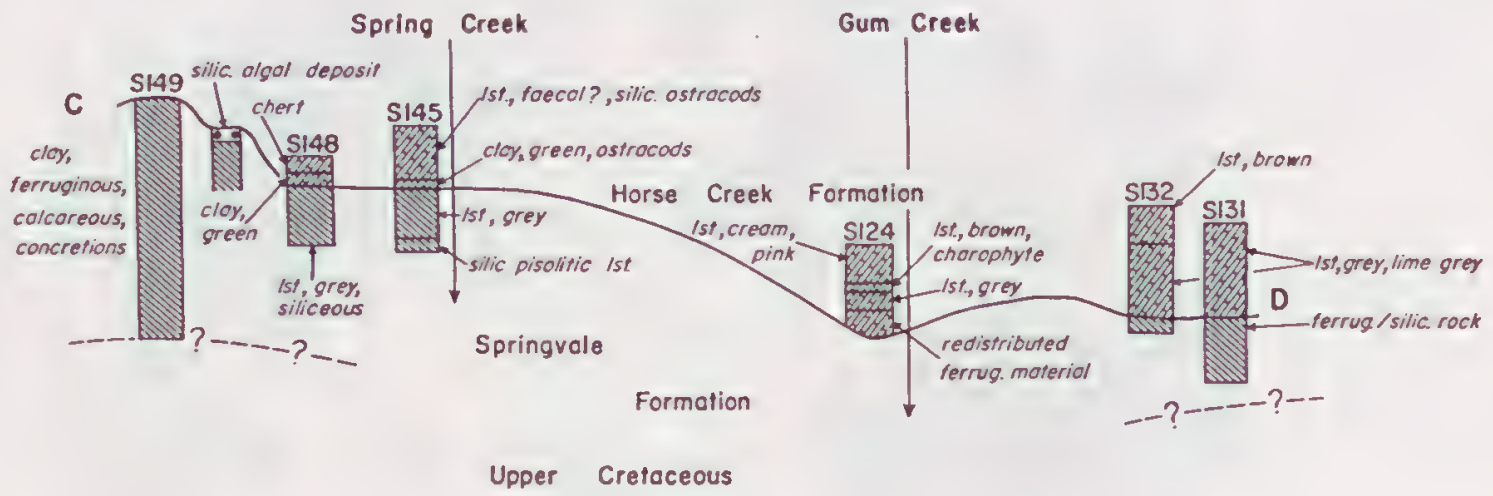
0 4 8 Miles (approx)

Vertical

0 40 80 Feet

Fig.5

SECTION C-D



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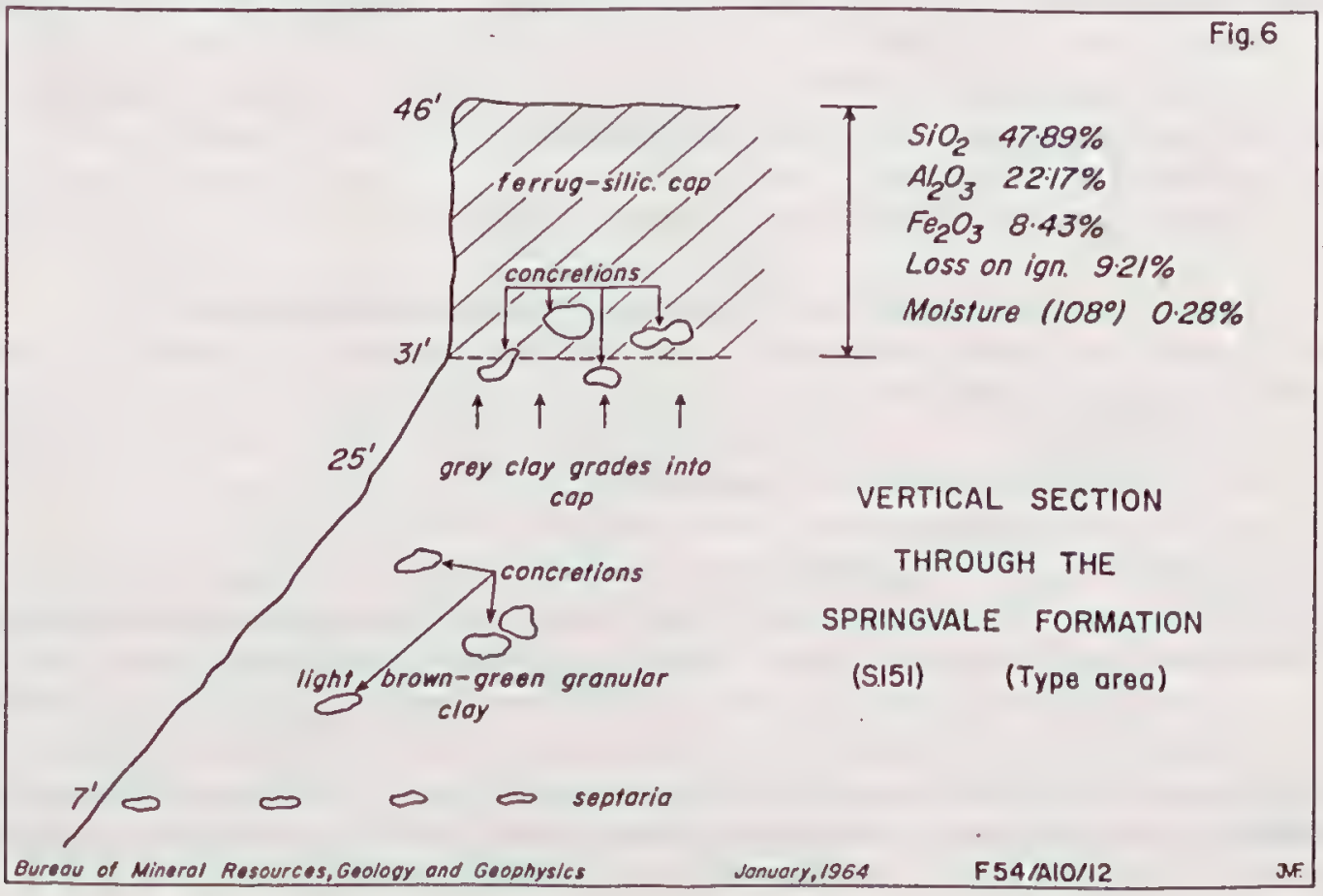
	Percent
Loss on ignition	15.1
Silica (SiO_2)	55.6
Alumina (Al_2O_3)	12.9
Ferric oxide (Fe_2O_3)	3.6
Calcium oxide (CaO)	7.5
Magnesia (MgO)	4.6
	99.3

Chemical alteration has also affected the clay sequences. This is illustrated in red-capped mesas on the western side of Spring Creek, e.g. in the type area (Pl. 1, Fig. 1). These red caps occur nowhere else in the Springvale area and are different from the alteration products of the limestone.

Figure 6 shows the sequence at S151 (type area) where the red cap is developed on a clay sequence. The pinkish red cap rock consists of an extremely porous fine siliceous boxwork densely impregnated by red iron oxide. It is 15 feet thick and grades downwards into light brown puggy swelling clay. This overlies a light brown to green clay in which aggregation has produced a granular texture. Concretions occur throughout the sequence as well as in the altered cap; near the base of the section, a thin band containing septaria occurs. At the northern end of the S151 mesa limestone concretions and lenses are commoner in the clays. Here a more open siliceous boxwork was developed in the cap, into which the limestone, densely iron-stained, persists. The softer material of the red cap has been powdered and used locally as a pigment for brown oil paint.



Calcareous concretions are the commonest secondary structures in the Springvale Formation and occur within both the limestone and the clay, ranging widely in size and form. In the limestone their diameters range from 0.8 to 0.4 mm. With rare exceptions they are simple spherical bodies showing little concentric or radial structure, and have a fine even-grained texture. Nuclei are rare, but at S108 to the south of Springvale, numerous ?molluscan shell fragments occur in the concretions. Differential silicification commonly affects the concretions but not the matrix, so that they stand out on the weathered surface of the rock. The silica is light brown, opaline, and is not isotropic owing to the inclusion of finely disseminated calcite particles.

In the clays the concretions range up to 2 feet in diameter and are grey to brown. Some are simple spherical bodies, but most are compound forms.

Septaria occur in the clay sequence at S151. They are light brown disc-shaped argillaceous-calcareous bodies with a reticulate to finely nodular ornamentation. The diameter ranges from 2 to 6 inches. Internally the septaria contain radial and concentric syneresis (shrinkage) cracks; most of the cracks have a papery coating of white, finely crystalline quartz with most of the void space free of deposit (Pl. 2, Fig 1), but more rarely the void space is filled with interlocking quartz crystals up to 1/4 inch long (Pl. 2, Fig 2.). The material of the septaria is dense towards the outside but becomes porous towards the centre.

Secondary structures intermediate in form between concretions and true septaria occur. These resemble solid concretions externally but have a poorly developed internal syneresis system (Pl. 3, Fig 1).

Spherulitic recrystallization of calcite occurs in the limestone and calcareous concretions in the ferruginized parts of the deposit. This type of recrystallization appears to be a late-stage process and post-dates all previously formed secondary structures. Thus spherulitic calcite forms around small concretions, cuts across concretion boundaries, and expels iron oxide to areas peripheral to the crystal growth. This type of calcite growth forms regular or compound spherical bodies, or is irregular in shape.

These post-depositional structures form in a definite sequence which persists throughout the deposit and can be summarized as follows:

1. formation of concretions;

2. differential silicification of some concretions by opaline silica;

3. ferruginization;

4. spherulitic calcite recrystallization.

Plate 3, Figure 2 illustrates this sequence. It figures a fine-grained limestone with small calcareous concretions (lower right) that have been partly replaced by opaline silica. The concretions and groundmass are lightly mottled by brown iron oxide. A large, compound, coarsely spherulitic calcite body of later origin (centre) cuts across the concretions and is surrounded by a rim of dark iron oxide apparently expelled by the recrystallization. The central area of the spherulite is slightly stained by iron oxide, but the peripheral area is clear and strikingly free of it. This outer clear zone adjacent to the excluded iron oxide rim is a constant feature of spherulitic growth in the formation.

Plate 4, Figure 1 is an example of spherulitic calcite growth in a previously ferruginized large calcareous concretion. The spherulitic crystallization was apparently initiated at a number of points and growth proceeded inwards as though into a cavity. The iron oxide of the rock (dark) appears to have been expelled by crystal growth into the central area. As before the spherulitic area is slightly iron-stained and the clear zone adjacent to the excluded iron oxide well shown. Plate 4, Figure 2 is a further example of late-stage recrystallization (non-spherulitic) in a ferruginized limestone. Crystallization has expelled iron oxide to the intercrystal areas.

The Springvale Formation was chemically altered by leaching (particularly of lime), silicification, and ferruginization. It is evident that lithology controlled the end products, for whereas the clays produced strongly ferruginous-siliceous rocks, the dominantly limestone lithology produced lightly iron-stained dense siliceous rocks. However, the end products are analogous: both consist principally of iron oxide and silica, the difference being only in the form and ratio of the constituents.

The chemical events are most simply explained by relating them to lateritization: lateritized Cretaceous sediments are extensive and occur within a few miles of the Springvale area. Fisher (1958) stated that typical laterite profiles in northern Australia consist of an upper derived soil zone, overlying a ferruginous zone, overlying a mottled zone, overlying a pallid zone, overlying fresh rock, with a siliceous zone occurring anywhere in the mottled or pallid zone. The red-capped hills in the type area exhibit a distinct zonation. The upper ferruginous-siliceous cap passes downwards into irregularly coloured red, brown, and green clays (Fig. 6). These two zones are analogous to the ferruginous and mottled zone of a laterite profile. The irregularly iron-stained siliceous rocks (from the dominantly limestone sequence) may represent the mottled zone of an eroded profile. However, the anomalous occurrence of large amounts of silica and calcareous rocks in these profiles must be explained.

In general, in this part of Western Queensland, the laterite profiles have unexpectedly high silica values throughout, when compared with those that would be expected from the 'theoretical profile' (Reynolds, 1960); but whereas the profiles on the surrounding Cretaceous rocks appear merely indurated by silica, the silica in the Springvale 'profile' forms a distinct silica rock. Furthermore, the preservation of calcareous concretions and small limestone bodies in the profile is unusual, since it would be expected that alkaline earths would be removed during lateritization. The alteration product of the limestone from the Springvale Formation (silica rock) is unlike those on other limestone sequences (e.g. in Playford, 1954).

The Springvale profile is considerably thinner than the lateritic profile developed on the Cretaceous sediments of the region. This suggests that the Springvale Formation may not have been exposed throughout the full cycle of lateritic weathering. Possibly the Springvale Basin was not initiated until a late stage of the lateritic cycle. If so, material subsequently deposited in the basin would consist of the products of the erosion of the immature lateritic profiles on the surrounding shales and limestones and possibly also the by-products of the leaching of the surrounding region by the prevailing lateritic weathering. Reworked lateritic material would ultimately have constituted much of the Springvale Formation and this, plus its subsequent exposure to weathering only late in the lateritic cycle, may account for the anomalous nature of its weathering profile.

The greatest exposed sequence of the Springvale Formation is in the Mungeroo Knobs to the east of Uka Tank, where 70 feet of granular concretionary clay crops out. The

Formation thins towards the east against the Goyder Range, where it overlies Moses Sandstone of probable Lower Tertiary age (W. Jauncey, pers. comm.) (Fig. 4).

Horse Creek Formation (Paten, 1960)

After chemical alteration and erosion of the Springvale Formation, the Springvale Basin became a depression in which lacustrine limestone, the Horse Creek Formation, was deposited. The basin migrated several miles to the east so that it overlapped the older Tertiary rocks to the east of the area of deposition of the Springvale Formation.

Horse Creek Formation is named after Horse Creek, a tributary which enters Spring Creek at Springvale Homestead. The type area and reference section for the formation are: Type area: From the crossing of Gum Creek on the Springvale-Diamantina Lakes road, about 2 1/2 miles upstream to the junction of a well defined creek coming in from the west, then 1 mile up this creek into a shallow gorge (Pl. 5, Fig. 1). Reference Section: Springvale airstrip at the homestead.

The formation caps the low plateau on which Springvale airstrip lies, and extends south-eastwards to about 5 miles east of the Diamantina River. It extends from near Uka Tank north-eastwards for about 28 miles. Outcrop covers approximately 200 square miles.

The Horse Creek Formation consists mainly of brown and grey richly fossiliferous limestone, which contains little clastic material, is very fine-grained, consisting essentially of chemically precipitated calcium carbonate. Partial recrystallization of the material gives a characteristic appearance to the rock in thin section, of darker areas of the original fine carbonate irregularly mottled by clear crystalline calcite mosaic (Pl. G, Fig. 1). Shelly material is commonly infilled with recrystallized calcite and some is veined by calcite mosaics. Finely divided carbonate crops out in a belt up to 30 feet thick along a scarp capped by solid limestone, about 5 miles north-west of Hunter's Gorge. In the type area (S124) a two-foot-thick bed of yellow-brown charophyte-bearing fine-grained argillaceous limestone crops out (Pl. 5, Fig. 1); elsewhere the limestone contains only trace amounts of interstitial argillaceous material and is poorly stratified, whereas bedding is well developed in the argillaceous limestone.

Faecal limestone occurs near the base of the sequence along the western margin of the outcrop. It consists almost entirely of small rod-shaped faecal bodies of fine-grained argillaceous limestone set in a limestone matrix (Pl. 6, Fig. 2). Ostracodes are common in this limestone and their shells are commonly filled with the faecal material. The localization of up to 10 feet of this material along the entire western margin, but not in the east, suggests that the faecal material was concentrated by wave or current action. Except along the eastern margin, a distinctive marker band of green clay, commonly not more than a foot thick and containing rare ostracodes, is invariably present in the base of the Horse Creek Formation. The band grades upwards and is partly brecciated into the overlying limestone of the formation.

The belt of faecal limestone has undergone an unusual silicification. At the top of the sequence is unaltered limestone; below this, the pellets, but not the calcite matrix, have been silicified. Near the base, the lime matrix is leached away to produce a porous, light-weight, white rock, composed largely of silica. It closely resembles tripoli (Pettijohn, 1957, p.433). Ostracodes are silicified and their shell structure preserved. The form of the

faecal pellets is preserved, and is responsible for the coarse texture of the rock, which otherwise has the general appearance of diatomite. Analysis, by the Queensland Government Chemical Laboratory, of one specimen of this material from the Springvale airstrip gave the following results (Analysis 1570/59 G.S.):

	Percent
Loss on ignition	13.7
Silica (SiO_2)	62.0
Alumina (Al_2O_3)	11.5
Ferric oxide (Fe_2O_3)	0.6
Calcium oxide (CaO)	9.2
Magnesia (MgO)	2.2
	99.2

This silicification is unusual, for, with all other observed Cainozoic silicification in Western Queensland, the degree of silicification decreased downwards from a surface (presumed to be at or near the surface of weathering). In this case particular beds near the base of the succession were silicified and the silicification increased with depth to the limit of the faecal lithology. The tripoli-type rock was not observed in any other Cainozoic basins in the area.

Some exposed parts of the formation have been silicified to form common opal, with minor veining by chalcedony. The opal in the limestone is honey-brown, whereas that in the green clay is dull green. Ostracode and gastropod shells are preserved in the opal and weather out in profusion on the surface of the rock. Thin laminae of dull to lustrous common opal occur in the leached faecal rock and exhibit an internal undulose structure which in some cases persists into the leached material.

The maximum observed thickness of 40 feet of the Horse Creek sequence is in a scarp on the western side of the Diamantina River, 5 miles north-west of Hunter's Gorge.

MARION BASIN

Sediments of the Marion Basin were deposited within an elongate north-south depression which extended from Windsor Park in the north to beyond the area of investigation in the south. Near Windsor Park it was about 10 miles wide, but it widened rapidly south of Boulia, and was about 40 miles wide at Latitude 24° S. The southern extent is not known, but the Marion Formation has been mapped in the Bedourie, Birdsville, and Betoota 1:250,000 Sheet areas (Reynolds, Olgers, & Jauncey, 1961).

The elongate shape of the outcrop of the Marion Formation, which extends southwards for at least 300 miles, suggests that the formation was deposited in the erosion valleys of a Tertiary drainage system analogous to that of the present Georgina River/Eyre Creek System.

Marion Formation (Casey, 1959)

A sequence of arenaceous sediments - the Marion Formation - was deposited in the Marion Basin. It is named after Marion Downs Station, a grazing property on the Georgina River, 40 miles south-west of Boulia. The type area is in hills 14 miles west of Marion Downs Homestead on the track from Marion Downs to Herbert Downs. A reference section is given 5 miles north-west of Strathelbiss Homestead, 14 miles north of Boulia.

Outcrop occupies two major areas. The northern area, between Windsor Park and Boulia, is separated from the southern, which extends southwards from Marion Downs, by the spread of alluvium at the junction of the Burke and Georgina Rivers. Outcrop in the southern portion is confined between the Mulligan and Georgina Rivers.

The formation has given rise to broad undulating grassy plateaux, which are being deeply dissected by the present cycle of erosion. Dissection is particularly active in the southern outcrop area, where the formation persists only as thin mesa cappings. Mount La Touche, Mount Tobin, The Knob, The Sisters, Mount Tarley, and 12-mile Mountain are all residuals capped by silicified Marion Formation.

The formation consists of quartz sandstone, ranging in grain-size from fine to very coarse, and fine quartz conglomerate. Grains are subangular to subrounded and consist of quartz with rare cream and dark chert; the chert occurs mostly in the coarser fraction. The derivation of the chert fragments from the Palaeozoic and older carbonate rocks to the north supports the hypothesis that the Marion Formation was deposited in a river valley with its source area in the north. Near the base of the sequence, valley fill occurs on a small scale and consists of fragments of the underlying lateritized sandy siltstone. A rough grading is indicated in the formation, the coarser fraction being mostly confined to the basal few feet.

The sequence has been almost completely silicified to form billy, which is described on P 23.

Bedding is poorly developed. Fine and coarse beds are interwedged occasionally in foresets. The formation is sub-horizontal except for the presence of initial dips of up to 20^{o}, which are commonly associated with valley-fill structures close to the base of the sequence.

The Marion Formation unconformably overlies the uneven eroded surface (mottled zone) of the lateritized Lower Cretaceous Wilgunya Formation (Pl. 6, Fig. 2). No junction with other Tertiary formations is exposed; at Windsor Park, where the Noranside Limestone overlies the Marion Formation, the junction is obscured by rubble from the two units. In bores near the Paravituari Waterhole, sandy sediments tentatively regarded as Marion Formation underlie the Austral Downs Limestone (Reynolds, 1960). The maximum observed thickness is 25 feet.

AUSTRAL DOWNS BASIN

The Austral Downs Basin occupied the Upper Georgina River Valley (including Pituri Creek), and except in the extreme south-eastern part, it was confined to the exposed shelf of Lower Palaeozoic carbonate rocks which lies to the north-west of the Great Artesian Basin. It extended from near Herbert Downs into the Northern Territory beyond Urandangi and Linda Downs. Lacustrine limestone, the Austral Downs Limestone, was deposited in the basin.

Austral Downs Limestone (Noakes & Traves, 1954)

This name was given by Noakes & Traves to limestone and chalcedony cropping out on Austral Downs, a property in north-eastern Northern Territory. The type locality is 'The Georgina Valley at Austral Downs and Urandangi'. Whitehouse (1940) recorded the occurrence of chalcedonic limestone along Pituri Creek. The Austral Downs Limestone crops out as elongated areas up to 12 miles wide within the valleys of Georgina River and Pituri Creek. The sequence is better exposed in Pituri Creek. Small areas of similar rocks are exposed on the western side of the Toko Range near Aroota Bore, to the south of Yardida Bore (both in the Northern Territory), and 8 miles north of Craven's Peak.

Outcrop along Pituri Creek, on Herbert Downs, east of the Georgina River on Roxburgh Downs, and in the Jimboola-Carrandotta area, is typified by elongate plateaux. In contrast, at Roxburgh Downs on the western side of the Georgina River, the formation outcrops as scattered small plateaux, ridges, and hills. This topography is clearly an expression of rock type: in the extensive plateau areas, the sequence is chalcedonic and is less eroded than the non-siliceous areas on the west side of the Georgina River at Roxburgh Downs. A typical scarped topography is produced by the dissection of the highly siliceous areas.

The plateaux along Pituri Creek are extensive - the one on which Glenormiston Homestead stands extends along the Creek for about 20 miles, with a maximum width of 3 miles. It is blanketed by a mantle of dark residual soil on which grows Mitchell Grass, but smaller plateaux of the formation are commonly capped by residual siliceous rubble and support only scrubby vegetation. In areas of little dissection, as in the Carrandotta area, the formation underlies extensive dark-soiled Mitchell Grass plains.

The Austral Downs Limestone sequence consists broadly of an upper chalcedonic cap overlying grey, cream, or white limestone, which overlies a zone rich in ferruginous detritus. These three divisions are gradational and one or more of them may be absent from any one outcrop area. The following section from near Pituri Creek, 5 miles north-west of Glenormiston Homestead, is typical for the formation.

Top. 15 feet chalcedony and siliceous limestone, silica content increases towards top of section and white and brown chalcedony weathers out on surface.

5 feet limestone, white, fragmental, with minor chalcedony.

5 feet limestone, impure, white, with some sandy ferruginous detritus.

5 feet ferruginous detritus, calcareous matrix, possibly some spring travertine textures.

Dolomite (Lower Palaeozoic)

Up to 10 feet of the basal part of the sequence is composed mainly of sandy ferruginous detritus derived from the erosion of the laterites. This part of the sequence varies from a sandy, nodular, dense to porous ferruginous rock with calcite veins and intergranular material, to an impure limestone with disseminated rounded ferruginous fragments and quartz grains coated with iron oxide. This rock contains some textures that are similar to those found in modern calcareous spring travertines in the area.

The detritus probably started to accumulate in the Georgina Valley before the lake in which the limestone was deposited had formed. During the lacustrine phase, while the limestone was being deposited, the detritus would have been reworked and redistributed to some extent, and incorporated into the base of the limestone by the precipitation of calcium carbonate in the interstices and by spring travertine. For this reason it was impossible to map the ferruginous detritus and the limestone as separate units.

The ferruginous material grades upwards into cream, grey, and white fine-grained limestone. Where the basal ferruginous layer is absent, the limestone commonly contains fragments of the underlying carbonate bedrock at the base. The limestone is composed of a chemical deposit of fine-grained carbonate, the texture of which is considerably modified by recrystallization. This produces a clotted appearance in thin section, due to an irregular arrangement of areas of dark fine-grained limestone and light crystalline calcite. Breakup of fine carbonate before consolidation, and subsequent cementation of the fragments by later deposited carbonate, produced large areas of limestone conglomerate or breccia up to 20 feet thick. Aggregation of pellets by thin coats of later deposited carbonate is a common feature. The fragmentation is probably due to collapse, caused by the instability of the freshly deposited sediments on an uneven floor of deposition. Pettijohn (1957) regarded such limestone conglomerates (pseudo-breccia) as resulting from the sloughing off of lime from the surface of the lime-depositing plants, e.g. charophytes; but this seems unlikely in the Austral Downs Limestone in view of their size and thickness. The conglomerates are best developed at Roxburgh Downs on the west side of the Georgina River.

The limestone passes upwards into an irregular silicified cap of white and bluish, translucent to opaque chalcedony. This cap seldom exceeds 15 feet in thickness, but at Aroota Bore and Lake Wonditti the whole sequence is silicified. The chalcedony forms massive bands up to 10 feet thick (Pl. 7, Fig. 2), veins, mamillate vug fillings, and irregular masses (Pl. 8, Fig. 1). The massive bands, in some cases, persist laterally and have distinct boundaries. The veins, vug fillings, and irregular masses form a complex reticule pattern within the silicified cap and include numerous residual limestone areas. Limestone textures (clotted, pellet) are commonly preserved in the chalcedony after all other traces of the limestone have disappeared. Traces of iron oxide in the chalcedony stain weathered surfaces brown. The scarps on the west side of Lake Wonditti illustrate this feature. The nature of the silicification and the origin of the silica are discussed on pages 25 and 26.

Apart from the sandy ferruginous base of the formation, clastic grains are rare and consist of subangular to subrounded quartz grains. Dendritic and platy manganese oxides occur in trace amounts in some areas.

Coarsely laminar-nodular limestone occurring as coating up to several inches thick on the surface and in joints of the Palaeozoic carbonates (particularly dolomite) is widely distributed throughout the Georgina Basin and should not be confused with the Austral Downs Limestone. It commonly contains sand and ferruginous detritus, and, rarely, is silicified to chalcedony. It is more widespread than the Austral Downs Limestone and is surface caliche, similar to material figured in Swineford, Leonard, & Fryre (1958).

Non-siliceous sections of the Austral Downs Limestone are poorly bedded (Pl. 8, Fig. 2), but in most areas, this stratification was destroyed by the post-depositional chemical redistribution of calcium carbonate and silica.

The Austral Downs Limestone overlies Lower Palaeozoic dolomitic carbonate rock in all outcrop areas examined. The unconformity is well exposed at a number of localities - the best observed being on the western side of Pituri Creek at Lake Wonditti, Glemormiston, where the siliceous Austral Downs Limestone overlies well jointed dolomite of the Ninmaroo Formation (Pl. 9, Fig. 1). At this locality, botryoidal chalcedony, similar to that of the overlying silicified limestone, fills vugs and the nautiloid fossils in the dolomite immediately below the unconformity.

NORANSIDE BASIN

The narrow Noranside Basin extended for at least 60 miles from Noranside in the north to the Hamilton River in the south. It was separated from another basin which developed within the upper Burke River Valley by a ridge of Cambro-Ordovician carbonate rocks at Digby Peaks. A smaller basin developed on Burnham Station about 16 miles east-north-east of Digby Peaks.

The Noranside Basin lay across the boundary of the Cretaceous sediments of the Great Artesian Basin and the Lower Palaeozoic carbonate rocks of the Black Mountain ridge. Its northern limit overlapped that of the Marion Basin, but the two basins existed at different times. The Springvale Basin is on the southern extension of its trend, but there is no evidence that the two were ever connected. The Noranside Limestone sequence, similar to the Austral Downs Limestone, was deposited in the basin.

Noranside Limestone (Casey, 1959)

The Noranside Limestone is named after Noranside Out-station, which is situated between the Burke River and Wills Creek, 50 miles north-north-east of Boulia. Casey (1959) described the two reference areas for the formation. They were described in detail in Casey et al. (1960) and are here repeated: (1) White siliceous limestone in a gully crossing the Boulia-Selwyn road 1.2 miles south of Old Noranside Well at Latitude 22°12' south, Longitude 140°04' east; (2) Pink, red, and white banded impure limestone at 6-Mile Creek, 1.4 miles south-south-east of 6-mile Bore (Corrie Downs) on Fort William Station and 0.4 miles south of an east-west dog-proof fence at Latitude 22°27' south, Longitude 140°12' east. Chalcedonic limestone was first noted in the Boulia area by Dunstan (1920). Whitehouse (1940) described silicified Late Tertiary limestone from Warenda and Fort William and a summary of this is given in Connah (1958).

Outcrop occurs in a belt 5 to 15 miles wide and in contrast to the Austral Downs Limestone exposure is poor, particularly in the south, where the formation is covered by an extensive plain of alluvium and black soil. Plates of limestone are widely scattered over the surface of the plain.

The sequence is similar to that of the Austral Downs Limestone. Redistributed pink and red lateritic detritus is concentrated within the basal 10 feet and the bulk of the sequence consists of white pellety fine-grained chemical limestone with veins and irregular areas of crystalline calcite. Pellets are commonly aggregated by later lime coats. Clastic quartz grains are rare except in areas rich in lateritic detritus. An irregular zone of chalcedony as massive bands, veins, and irregular masses tops the sequence. It passes downwards into unaltered limestone. Silicification is commonly differential, calcite mosaics and veins being replaced more readily than the fine-grained precipitated lime.

The lower part of the sequence shows a fine bedding which is commonly disrupted either by desiccation or by the action of organisms. Elsewhere the deposit appears poorly stratified.

The Noranside Limestone overlies the lower Palaeozoic and Cretaceous rocks of the area and is covered in part by two ages of alluvium - the younger being that of the present river system. It apparently overlies the Marion Formation at Windsor Park. The greatest thickness observed was 45 feet at reference area (1).

SINTERS

Siliceous sinters crop out at Mount Coley, Mount Whelan, Sugarloaf Hill, and near Boulia on Alderley and Stockport Stations (Fig. 2). These are collectively known as the Mount Coley Sinter (Casey, 1959), although there is no suggestion that they ever existed as a continuous deposit. Sinter forms sharp hills and low rises and overlies unconformably the lateritized Lower Cretaceous Wilgunya Formation.

The sequence consists of brown and white cellular opaline sinter, commonly with ferruginous inclusions (derived from the erosion of the laterites), and milky blue and white chalcedony. No bedding is evident, but massive white chalcedony, when preserved, overlies the sinter.

The sinters are thought to have been deposited in small depressions from siliceous spring waters derived from a fractured aquiclude (Wilgunya Formation) of the Great Artesian Basin. Faulting occurs below the sinter in the Wilgunya Formation at Mount Whelan. Estimated thicknesses for the 'formation' are Mount Coley 120 feet, Sugarloaf Hill 60 feet, and Mount Whelan 35 feet.

PALAEONTOLOGY AND ENVIRONMENT

Springvale Formation

Up to 15 feet of silicified probable algal limestone with rare residual limestone areas crops out as discontinuous arcuate ridges to the west and south-west of Springvale Homestead along the Black Mountain structural line and as expanses of rubble between there and Gum Creek (Fig 3). Most of the ridges have steep westerly slopes and dip at a low angle to the east, probably as a result of post-depositional movement, or possibly because the algal limestones were small bioherms. Outcrop is rubbly because the algal mass has broken up into colonies, concentrically layered and ranging in shape from simple sub-spherical forms to complex irregular bodies (Pl. 9, Fig. 2). Commonly growth is elongate in one direction with small outgrowths in which the layered structure persists.

Partly silicified algal limestone crops out in hills on the north side of the road from Springvale to Diamantina Lakes about 10 miles from Springvale Homestead (S120). This material consists of alternating concentric layers of dark and light grey sandy limestone (Pl. 10, Fig. 1). The light grey bands are of 'spongy' limestone, made dense by later calcite and silica infilling and replacement. The dark grey bands are finer-grained and grade outwards into the spongy mass. Silicification is more intense in the fine bands, which weather out as ribs on exposed surfaces.

Recrystallization has, in most cases, destroyed the structure of the individual algae; however, rare filaments and solid spherical bodies were observed in thin section. Filaments are fragmentary, simple and unbranched, ranging in diameter from 30 to 50 microns. Crosswalls were observed only rarely. The filaments are filled by calcite mosaic. The spherical bodies are solid and composed of uncleaved calcite. They range in diameter from 12 to 32 microns, with most towards the upper limit of the range. The nature of these bodies of organic appearance is unknown; they may be unusual calcite infillings of unicellular algae.

Thin-shelled, plane-spired gastropods occur in chert (silicified limestone) and limestone about 12 miles south of Springvale Homestead (S108). Other thin-shelled fragmentary molluscan remains occur in grey limestone below the Horse Creek Formation about 16 miles south-south-east of the homestead (S145).

The presence of massive calcareous algal deposits in the Springvale Formation suggests that it was deposited in fresh or brackish water. Bradley (1929) described a similar, but much larger, sequence of algal deposits, limestone, and clays from the basal 700 feet of the lacustrine Tertiary Green River Formation from the western United States of America.

Horse Creek Formation

The Horse Creek Formation is by far the most fossiliferous of the Tertiary lake deposits in western Queensland and the one in which the lacustrine origin is most obvious. Fossils include ostracodes, gastropods, charophytes, and probable faecal pellets.

Smooth-shelled ostracodes are the commonest fossils and occur in profusion throughout the sequence. They can be collected from most outcrop areas, particularly in the upper silicified levels, where they weather out on the surface of the plates of common opal. Apparently only one form is present.

Gastropods occur in siliceous limestone rubble near the eastern edge of the Springvale plateau on the west side of Gum Creek, 16 miles south-east of Springvale Homestead and 5 miles north-east of Merrion Downs Bore (S123). Two forms occur, a low spiralled form up to three-quarters of an inch in diameter and a small thin-shelled turreted form up to a quarter of an inch long. Charophyte gyrogonites (female fruiting bodies) are very abundant in a fine-grained creamy brown argillaceous limestone in the type area near Gum Creek (S124). Leaching has removed the gyrogonites, leaving moulds which preserve the characteristic spiral structure. No stems or other parts of the plant were observed. Faecal pellets are concentrated in vast numbers along the western margin of the formation. Excellent exposures occur on the east side of Spring Creek below the Springvale Airstrip. They consist of calcareous-argillaceous material and are preserved in limestone, which is largely silicified and leached. Partly silicified pellets were separated from the calcareous matrix by slow leaching in dilute acetic acid.

The pellets are fragmentary, straight rod-shaped bodies, 1 to 1 1/2 mm. long and about 1/2 mm. in diameter (Pl. 10, Fig. 2). They have a well-defined longitudinal groove, and some have a corresponding flattening or shallow groove on the opposite side. The outer surface of some of the pellets is ornamented with an indistinct low-angle spiral.

The parent organism for this materal was not found, and was presumable soft-bodied. Ostracode shells filled with faecal material are found, but seem too small to be the origin of the faeces.

Marion Formation

The only fossil collected from the Marion Formation is rare though widespread silicified wood. Smaller specimens may have been redistributed from the Cretaceous sediments of the area, but concentrations of large pieces are almost certainly first-cycle. Carter (1959) examined two probable first-cycle specimens from 6-Mile Bore on Strathelbiss Station, 9 miles north-north-east of Boulia, and identified the following:-

1. Mesembrioxylon - Podocarp or possibly non-resinous Cupressinoxylon

2. Cupressinoxylon - very similar to Arthrotaxis.

These fossils give no indication of environment of deposition; however, sedimentary structures in the formation, discussed previously, suggest that it was lacustrine or fluviatile.

Austral Downs Limestone

Although the Austral Downs and similar limestones are widespread in western Queensland, fossil remains in them are rare, probably because forms have been destroyed by calcite recrystallization and subsequent silicification. Whitehouse (1940) regarded these limestones as unfossiliferous, and stated that they were probably surface soil limestones formed between two periods of lateritization. Fossils indicative of a lacustrine origin have now been found in three limestones, and it seems likely that other occurrences referred to by Whitehouse will also be found to be fossiliferous after detailed thin-section examination.

Fossils from the Austral Downs Limestone include charophyte and other algal remains, plant tissue, ostracodes, and foraminifera. Charophyte stems and fruiting bodies (gyrogonites) and rare ostracodes occur in limestone at the Carrandotta Homestead Tank, about 48 miles north-west of Roxburgh Downs on the eastern side of the Georgina River. The gyrogonites have affinities with those of the modern genus Chara (P.R. Evans, pers. comm.).

The siliceous limestones near Aroota Bore on the west side of the Toko Range in the Northern Territory contain probable charophyte stems (Pl. 11, Fig. 1) and fragmentary, simple, unthickened cellular plant tissue (all observed in thin section only). The fossils are from near the base of this sequence, which contains much redistributed ferruginous lateritic material. Tertiary charophyte fructifications and stem structure are illustrated in Horn of Rantzien (1959).

Foraminifera were collected from only one locality. Abundant well preserved forms associated with rare ostracodes occur at the top of a small plateau at the junction of Manner Creek with the Georgina River on Roxburgh Downs; the host rock is a hard manganiferous breccia. The foraminifera could be examined only in thin section (Pl. 11, Fig. 2). Rotaline and globigerine forms were present, but specific identification and age determination were impossible (Dr Irene Crespin, pers. comm.).

The foraminifera may be remanie fossils; but the only possible marine source rocks from which they could be derived are the Lower Cretaceous clays of the Great Artesian Basin, in which globigerine and rotaline forms occur. These clays were deeply lateritized before the deposition of the Austral Downs Limestone, and hence the derivation of fresh calcareous tests from them is considered unlikely. They are believed, therefore, to have lived within the

the environment of deposition of the limestone. Glaessner (1945) indicated that foraminifera, including rotaline and doubtful globigerine forms, occur in continental brackish environments. Ludbrook (1953) reported abundant rotaline forms associated with ostracodes and charophytes from Sub-Recent sediments in Lake Eyre in South Australia.

Modern charophytes are small, aquatic plants which live entirely submerged in clear, quiet or slowly moving bodies of water. They inhabit fresh or brackish water, but one species shows tolerance to high salinity (18 parts per thousand chloride in the Baltic Sea). Charophytes have wide tolerance to lime concentration, but pH is the controlling factor, most charophytes being confined to alkaline water. Some, however, grow in acidic water, while others exist in fluctuating acid-alkaline water (Peck, 1957).

Hence the association of charophytes, foraminifera, and ostracodes suggests a brackish continental lacustrine environment for the deposition of the Austral Downs Limestone. The low percentage of clastic material in the Austral Downs Limestone, except in the derived lateritic detritus at the base, suggests that it was formed during a period of low rainfall. This was also suggested by Whitehouse (1940) and Noakes et al. (1959). It is thought that water for the lake or lakes was derived initially from springs rather than from rainfall, which is supp-orted by the presence of probable spring travertine textures within the basal detrital zone. These textures probably reflect spring action during an early phase of the rising watertable as the lakes were forming.

Noranside Limestone

Fossils include ostracodes, plant tissue, gastropods, diatoms, and possibly other algae. Ostracodes do not weather out on the surface of the rock and were observed only in thin sections of rocks from near Noranside Homestead.

Thin-shelled turretted gastropods, plant tissue, and diatoms are common in limestone containing ferruginous detritus along 6-Mile Creek near the Fort William/Corrie Downs boundary. The best exposure is at a fence corner, 1.4 miles west of 6-Mile Bore on Corrie Downs. Forms identified from this locality are (Dr Crespin, pers. comm.);

gastropod	:	?Bulinella sp.
diatoms	:	Diploneis cf. elliptica
		Epithema sp.
		Navicula sp.

The diatoms present are identical with those from deposits at Innot Hot Springs in north Queensland, at South Yarra in Victoria, at 8-Mile Creek in South Australia, and in various spring and lake deposits in south-west Western Australia (Crespin, 1947).

A similar environment of deposition to that of the Austral Downs Limestone is postulated for the Noranside Limestone.

AGE AND RELATIONSHIPS

The suggested relationships of the formations to one another based on all avail-able information is set out in the table on page 20. The role of lateritization and palaeonto-logy in these determinations is discussed below.

DIAGRAMMATIC RELATIONSHIPS OF TERTIARY FORMATIONS

Post-Laterite	Springvale Basin	Marion Basin	Austral Downs Basin	Noranside Basin
	Horse Creek Formation		Austral Downs Limestone	Noranside Limestone
		Marion Formation		
Laterite	Springvale Formation			
Bedrock	?Lower Tertiary, Upper and Lower Cretaceous	Lower Cretaceous	Lower Palaeozoic Carbonates	Lower Cretaceous and Lower Palaeozoic Carbonates

Various ages have been assigned to lateritization in Australia. For example, Bryan & Jones (1946) regarded the period of laterite formation as Miocene, whereas Whitehouse (1940) deduced two periods of lateritization during the Pliocene.

It has been suggested also that lateritization is still active in some parts of Australia or has recently been so, though on a less intense scale.

Lateritization was certainly active in Australia during these times. However, I believe that the formation of laterite profiles (i.e. the preservation in situ of the products of chemical deep weathering) is controlled, in any one area during an overall time of lateritization, by the stability or instability of the surface exposed to weathering at that time: gentle regional earth movements during a time of lateritization would be expected to upset the surface stability, resulting in the erosion of the developing laterite profiles, while laterite continues to form in adjacent regions. Thus, the time limits of the formation of lateritic profiles may change from region to region and caution must be exercised in using the laterites as agents of correlation. Hence, it is contended that:

(a) The products of lateritization can be used satisfactorily only in local correlation. The table (Diagrammatic Relationships of Tertiary Formations) is based partly on this principle.

(b) The products of lateritization can be used in giving relationship to the time scale only when the limits of lateritization can be locally established. For example, Condon (1954) was able to show, by the study of lateritized marine sediments of known age, that in the Carnarvon Basin of Western Australia lateritization took place from the Eocene to the late Miocene or possibly Pliocene.

There is no evidence to establish the local age limits of lateritization in this area of western Queensland, and so laterite cannot be used to date the post-Cretaceous sediments here.

Fossils are not plentiful and the taxonomy and range of those that do occur are imperfectly known; but such fossil evidence as is available has been used in estimation of age.

The Springvale Formation is probably the oldest of the Tertiary Formations here described. It overlies Wilgunya Formation (Aptian and Albian), the Winton Formation, regarded as Cenomanian or younger by Whitehouse (1954), and, in the Goyder Range, the Moses Sandstone of probable Lower Tertiary age (W. Jauncey, pers. comm.).

On the grounds of position, type of deposit, and lithology, the Austral Downs and Noranside Limestones are regarded as equivalents. The Noranside Limestone overlies the Marion Formation on Windsor Park. Diatoms from the Noranside Limestone are late Tertiary or early Quaternary (Dr Irene Crespin, pers. comm.), and charophytes from the Austral Downs Limestone have modern affinities. On this basis, it is suggested that these limestones are late Tertiary or early Quaternary in age.

There is no direct evidence for the age of the Horse Creek Formation. It unconformably overlies the Springvale Formation, and may be the time equivalent of the Noranside Limestone (tectonically related). A late Tertiary or early Quaternary age is suggested.

The Mount Coley sinter overlies the eroded laterite profile developed on the Lower Cretaceous Wilgunya Formation. As do the Tertiary units of the region, it caps residual hills at elevations of up to about 100 feet above the present general land surface. For these reasons a post-lateritic Tertiary age is presumed for the sinters.

TECTONICS

The post-Cretaceous tectonic history of the area is characterized by broad regional warping, associated with minor movement along the old Burke River Structure. Because of the broad nature of the warping it is difficult to recognise its effects in the field, particularly in the Great Artesian Basin, where exposure is poor.

The Burke River Structure (Pl. 13) is the expression of a tectonic belt which was active at least from the Lower Palaeozoic to the Tertiary. In the Black Mountain area, 35 miles north-east of Boulia, it is a north-north-west-trending graben bounded by the Black Mountain Fault on the west and the Momedah Fault on the east (Casey et al., 1960). In the Springvale area, 80 miles south of Black Mountain, surface faulting in the Cretaceous sediments of the Great Artesian Basin shows the southern extension of the Black Mountain Fault. There is no evidence of faulting along the projected line of the Momedah Fault at Springvale.

It is assumed that the Springvale Basin was initiated by movement related to the Black Mountain Fault. The Springvale Formation, which was the first formation deposited in the basin, is disturbed by minor faulting with a north to north-west trend within the Black Mountain Fault Zone. To the east of the zone minor warping occurred. The Black Mountain Fault Zone was not observed south of Uka Tank (20 miles south of Springvale Homestead) and is apparently truncated here by a marked north-north-easterly fault system associated with minor folding. This north-north-east trend parallels the axes of the post-Cretaceous fold structures of the Innamincka-Betoota Region (Sprigg, 1958), in the south-west portion of the Great Artesian Basin and contrasts with the north to north-north-west trend of the major structures (Burke River, Toko) in the Palaeozoic and older rocks of the Boulia Shelf.

The Horse Creek Formation was deposited after the deformation of the Springvale Formation since it fills synclinal warps and thins over anticlinal areas in the older formation. With the exception of possible tilting on a regional scale, there is no evidence of deformation in the Springvale Basin after the deposition of the Horse Creek Formation.

On the Boulia Shelf the Austral Downs Limestone was deposited in the present valley of the Georgina River, in a lake presumably formed as the result of warping in the Great Artesian Basin to the south. The Noranside Basin, situated across the boundary of the Lower Palaeozoic sediments of the Black Mountain Ridge and the Lower Cretaceous sediments of the Great Artesian Basin, may have been initiated by similar warping or by movement associated with the adjacent Burke River Structure.

After the deposition of the Austral Downs and Noranside Limestones there was a low regional tilt of the Boulia Shelf to the south which presumably initiated the present drainage system. This tilt was an effect of the Selwyn Uplift (Öpik, 1960, p. 93) and is evidenced by the difference in the elevation of the base of the limestone along the length of the deposits: about 130 feet between Tobermory and Glenormiston (70 miles), about 90 feet between Jimboola and Glenormiston (55 miles), and about 200 feet between Noranside and the Hamilton River measured along the length of the Noranside Limestone (60 miles). These figures indicate that the tilt on the Noranside Limestone is greater than that on the Austral Downs Limestone.

SILICIFICATION

The late Tertiary geological history of the Boulia region was marked by intensive silicification of the superficial rocks. The Marion Formation, the Noranside and Austral Downs Limestones, and the siliceous sinters are strongly silicified. Surface silicification of the Horse Creek Formation was less intense, probably because the original limestone contained little silica. Silicification of the Springvale Formation is not of the surface type and probably it was not exposed to weathering after the deposition of the overlying Horse Creek Formation until the present cycle of dissection. The Noranside Limestone overlies the silicified Marion Formation at Windsor Park. However, the contact is completely obscured by rubble and it is impossible to deduce whether two periods of silicification are represented or whether the formations were silicified together to form a single profile.

Silicification of the Marion Formation

The Marion Formation, which consists of poorly stratified quartz sandstone and grit, overlies the mottled zone of the truncated laterite profile which was developed on the Lower Cretaceous Wilgunya Formation. The younger formation is almost completely silicified to form the siliceous rock 'billy', and forms part of the extensive billy sheet of inland Australia which on dissection has given rise to the great gibber plains or stony deserts.

The products of silicification form a distinct profile up to 30 feet thick on the Marion Formation, in which the degree of silicification decreases downwards from the upper levels of the formation to the base. Thus, at the base of the formation, the porous gritty sandstone texture and sedimentary structures are preserved. This basal material grades up into a hard, dense, but in some cases porous, brittle billy in which the nature of the original sediment is destroyed. Corresponding with the upward increase in intensity of silicification, grain size and grain contact decrease towards the top of the profile. In the upper levels of the profile, a pseudo-conglomerate texture is developed, in which apparent pebbles of billy are aggregated in a matrix of the same material. These pseudo-conglomerates, which are not silicified conglomerate of the original sediments, characteristically occur in smooth-surfaced vertical columns up to four feet in height and several feet across (Pl. 12, Fig. 1).

The lithology of the billy depends upon the intensity of silicification and hence varies from the base to the top of the profile. At the base, where sedimentary textures are preserved, the rock may be bonded by layering of siliceous and/or ferruginous cements that fill the intergranular spaces, and the rock differs little in general appearance from the original sediment. Elsewhere in the profile, open-space filling by cements is rare and the rock consists essentially of poorly sorted chemically corroded quartz and other siliceous grains set in a groundmass of amorphous silica. The corroded grains present deeply embayed to sharply angled outlines and commonly the boundary between grain and matrix is gradational. Grain contact is low and the matrix commonly exceeds 30 percent of the total rock. The matrix consists of chalcedonic or opaline silica or forms intermediate in properties between the two; intermediate forms observed exhibit the spherulitic interference pattern of chalcedony with the low refractive index of common opal. The colour of the billy ranges from grey to honey-brown or red-brown and depends upon the quantity of iron oxide in the matrix.

The silicification of the Marion Formation is a post-depositional feature, since normal sedimentary structures and textures are commonly preserved below the gradational profile of silicification developed on it. In the absence of any evidence of an outside source

of silica, the corrosion of the siliceous grains of the formation within the silicified profile indicates that the silica of the matrix of the billy was derived from the constituent grains themselves. It follows that the silicification involved the chemical transformation of the siliceous grains of the parent rock to opaline or chalcedonic silica. This transformation is regarded as the key to the formation of billy on siliceous rocks.

The quartz grains in the rock in the higher parts of the billy profile are placed with complete irregularity in the siliceous matrix, and the rock texture bears little or no relationship to that of the original sandstone (Pl. 12, Fig. 2). Fragments of the same grain when cut by silicification rarely have the same optical orientation, and corroded surfaces of different grains lie in close proximity, occupying less space than they would have required in the original sandstone framework before they were corroded and reduced in size. The grains have therefore moved during silicification, and because grain fracture is rare, a gel phase allowing this movement was probably involved. Such a phase would allow for any change in volume that might take place in the transformation of the quartz grains of the original sandstone to the amorphous silica of the billy matrix. The columnar jointing producing the billy columns at the top of the profile may have resulted from tension caused by the drying out of the gel phase.

The basal portion of the Marion Formation commonly contains granular iron oxide or is iron-stained. The iron oxide is thought to be of detrital origin and derived from the erosion of the laterite profile developed on the Wilgunya Formation, on part of which the Marion Formation was deposited. The iron oxide has been concentrated to a minor degree during the silicification, and is the source of the brown colour of the billy in some areas. Movement of silica and iron oxide during silicification is further evidenced by the presence of opaline fracture-fillings impregnated with iron oxide in the Wilgunya Formation immediately below the silicified Marion Formation at 12-Mile Mountain. Wherever, between Windsor Park and the southern limit of the area under discussion (Pl. 13), the base of the Marion Formation was observed, it unconformably overlies the dissected laterite profile (mottled zone) developed on the Cretaceous sediments of the Great Artesian Basin. The same sort of clear break between the lateritization and the billy formation, with erosion and the deposition of sediments intervening, was noted by Jessup (1960) in the south-eastern portion of the Australian arid zone. Elsewhere, authors - for example Condon (1954), Wopfner (1960), and Whitehouse (1940) - have regarded the billy as a siliceous zone within the laterite profiles. It may be significant that, in the examples illustrated by Condon and Wopfner, the billy zone, when present, was at the top of the lateritic profile. Detailed investigation is required to assess the full significance of the break between the development of the laterite profiles and the formation of the billy crust in the Boulia region and elsewhere. Silicification to form billy was not confined in the Boulia region to the Marion Formation; billy formed on quartzose sediments of the Lower Cretaceous Longsight Sandstone at Mount Ninmaroo, on Ordovician sandstone in the Toko Range, and on ?Permian fluvio-glacials near Aroota Bore, Tobermory. From this it is concluded that silicification to form a billy profile is the result of chemical weathering of all exposed quartzose rocks in response to a particular suite of climatic conditions. As both weathering products are so commonly associated the billy profiles possibly owe their origin to climatic conditions closely related to those causing lateritization.

Silicification of the Austral Downs and Noranside Limestones

The Austral Downs and Noranside Limestones characteristically have a chalcedonic cap (Pl. 7, Fig. 2; Pl. 8, Fig. 1). The presence of residual limestone and limestone structures within the cap, as described on page 14, indicates that the limestone has been silicified,

and that the siliceous cap is not a depositional feature. The profile of silicification is analagous to the billy profile imposed on the Marion Formation in that the degree of silicification decreases downwards from the top of the sequence. There is no obvious outside source for the silica, and it must be concluded that the silicification involved the concentration of the silica from the originally siliceous limestone into the upper levels of the sequence. The absence of a siliceous cap on the Austral Downs Limestone in some areas may be due to low silica content in the original limestone in those parts. Silicification was probably in response to the same type of weathering environment that caused the silicification of the Marion Formation; however, there is no positive evidence to show whether or not the two units were silicified comtemporaneously. Whitehouse (1940) regarded the silicification of the limestone as indicative of a second period of lateritization in the area.

The presence of large quantities of silica within the original limestone presents many problems because calcium carbonate and silica are soluble at different pH values. It is possible that silica was extracted from solution by siliceous organisms such as diatoms or sponges: but diatoms in the limestone are rare, and siliceous sponges are unknown. On the other hand, these organisms, if originally present, would tend to be destroyed along with calcareous fossils during the post-depositional redistribution of silica and calcium carbonate.

Australian distribution of siliceous limestone

Limestones similar to the Austral Downs and Noranside Limestones are widely distributed in Australia. In Queensland, numerous outcrops occur between Boulia and Birdsville, the best known being at Cacoory and Old Roseberth (Whitehouse, 1940). Reynolds, Olgers, & Jauncey (1961) show the position of all known outcrops of chalcedonic limestone in this region. Their use of the term 'Austral Downs Limestone' for these is considered inadvisable since there is no evidence to suggest that there was ever depositional continuity between them and the Austral Downs Limestone several hundred miles to the north. Two small previously unrecorded outcrop areas occur about one and ten miles south of Breadalbane Homestead on the Boulia-Bedourie road.

The Carl Creek Limestone (Jack, 1896), at Riversleigh in north-west Queensland, was deposited in an area of Cambrian Limestone in the Gregory River Valley. It consists of lacustrine or spring limestone with abundant fossil bones and gastropods. Since the deposit overlies lateritic detrital material, it may be of similar type to the Austral Downs and Noranside Limestones, but it lacks the characteristic silicification. The Carl Creek Limestone is described by Whitehouse (1940) and has been referred to by Daintree (1872), Jack (1896), Cameron (1901), Ball (1911), David (1914), Dunstan (1920), Connah (1958), Paten (1960), and Carter, Brooks, & Walker (1961). Noakes & Traves (1954) described it under the name 'Verdon Limestone'.

Konecki, Dickins, & Quinlan (1958) described chalcedonic limestone from the Wooramel River region of Western Australia. The sequence is 30 feet thick with a thin band of shale and red-stained quartz greywacke at the base. This deposit, which is not closely related to calcareous bedrock, was regarded as a lacustrine deposit related to the last cycle of erosion.

Traves, Casey, & Wells (1956) described the Oakover Beds, a chalcedonic limestone sequence up to 100 feet thick in the Canning Region of Western Australia. A five-foot band of derived lateritic detritus marks the base of the deposit. Basement to the Oakover

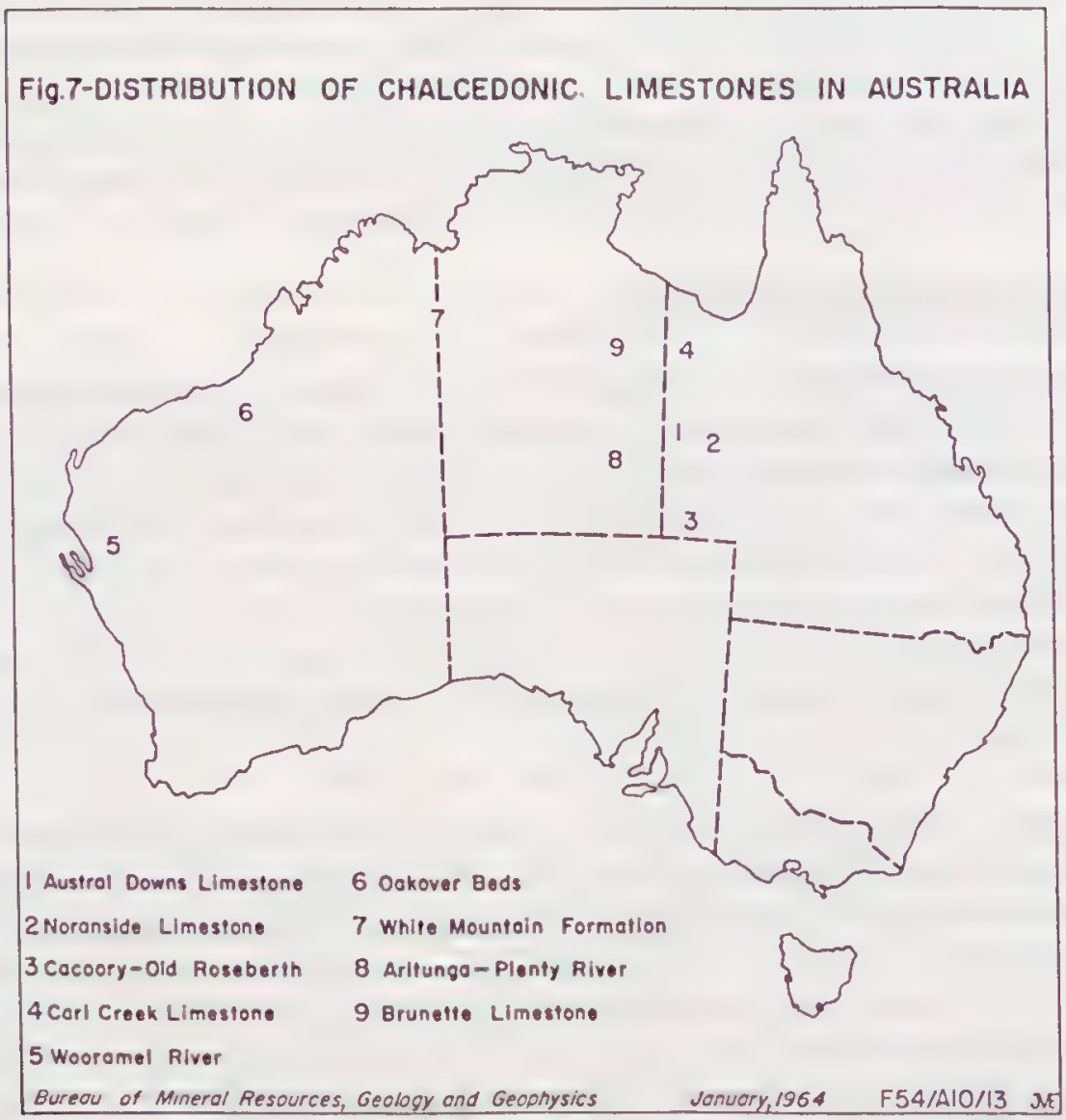


Fig.7-DISTRIBUTION OF CHALCEDONIC LIMESTONES IN AUSTRALIA
1 Austral Downs Limestone
2 Noranside Limestone
3 Cacoory-Old Roseberth
4 Carl Creek Limestone
5 Wooramel River
6 Oakover Beds
7 White Mountain Formation
8 Arltunga-Plenty River
9 Brunette Limestone
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January, 1964
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Beds includes dolomitic limestone, tillite, and metamorphics. The authors concluded that these beds were a chemical lacustrine deposit formed in the old Oakover River Valley. Casey & Wells (1964) described a similar formation, the Lawford Beds, in the North-eastern Canning Basin.

The White Mountain Formation from the Ord River region of Western Australia (Traves, 1955) consists of up to 370 feet of chert, siltstone, and marl containing gastropods, algae, foraminifera, sponges, ostracodes, and insects. It overlies sandstone basement. Traves thought that the formation was of the same type as the Austral Downs Limestone, but pointed out the significant difference in the high proportion of clastics in the White Mountain Formation.

Madigan (1932) and Smith, Vine, & Woolley (1960) described up to 90 feet of gastropod-bearing chalcedonic limestone, limestone, and rare clastic sediments - the Arltunga Beds - from the Arltunga Plenty River region of the eastern Northern Territory. The deposit contains lateritic detritus at the base or overlies ferruginous laterite in situ. The Arltunga Beds overlie a basement of Archaean gneiss.

Noakes & Traves (1954) described the Brunette Limestone, a chalcedonic limestone similar to the Austral Downs Limestone from the Barkly region of the Northern Territory.

Relationship of the siliceous limestones to lateritization

The Austral Downs and Noranside Limestones overlie carbonate rocks which provide a ready source of carbonate for their deposition. A major area of the Oakover Beds (Traves et al., 1956) also overlies carbonate bedrock, and it is significant that these three deposits are by far the largest of those described. A number of chalcedonic limestones, however, are not related to calcareous bedrock; for example those between Boulia and Birdsville and in the Wooramel River, area which overlie argillaceous sediments, the White Mountain Formation, which overlies sandstone, and the Arltunga Beds, which overlie metamorphics.

In almost every case, irrespective of bedrock, there is a close relationship between the chalcedonic limestone and the laterite; i.e. the limestones overlie ferruginous lateritic detritus, or rest directly on the ferruginous zone of the laterite in situ. This is regarded as the key to the origin of the chalcedonic limestone of this type. A number of authors have noticed this relationship in the past; for example, Konecki et al., (1958), Traves (1955), Noakes & Traves (1954), and Noakes, Carter, & Opik (1959); and have regarded lateritization as the source for the calcium carbonate and silica.

Noakes et al. (1959), when considering the source of silica and carbonate in the Austral Downs Limestone, suggested that 'The calcium carbonate and silica freed by the processes of lateritization were carried into a lake..... and were deposited during a subsequent arid period'. Since the laterite was to some extent dissected before the deposition of the limestone, the persistence of such a lake seems unlikely. On the other hand, ample storage for carbonate and silica released by lateritization is provided by underground water which may be released from springs during a subsequent lacustrine phase.

Hence the lime carbonate and silica released by the lateritization of the country rock provide the source materials in the formation of the chalcedonic limestones. However, where the bedrock is carbonate, the proportion of available carbonate is enormously increased, and so there is a direct relationship between the size of the deposit and the carbonate content of the bedrock.

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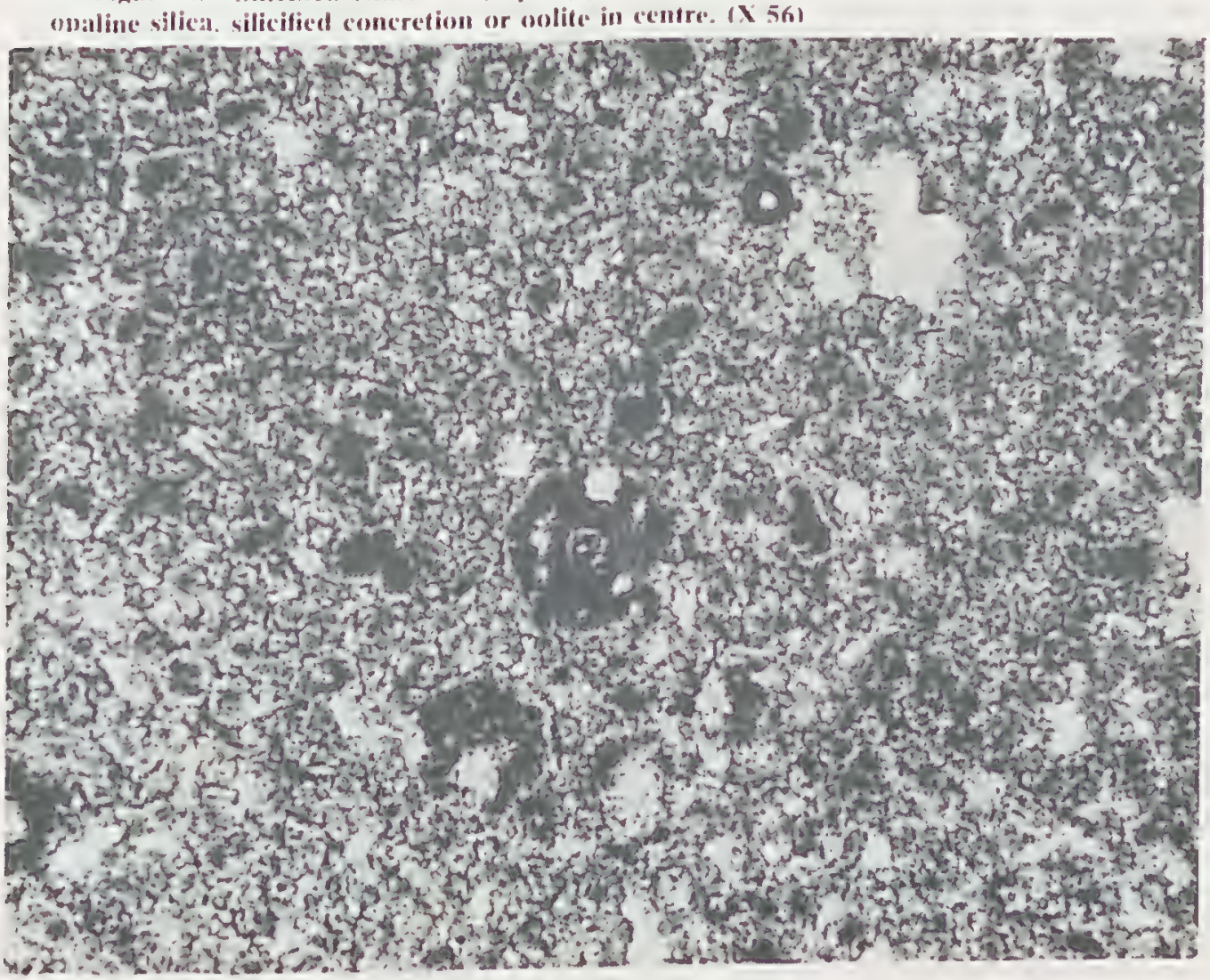
Figure 1.—Dissected ferruginous-capped plateau of the Springvale Formation, 2 miles south-west of Springvale Homestead (type area). (Fig. 7 is a section through the plateau in this area)

Figure 2.—Silicified ?limestone, Springvale Formation. Clotted texture of iron-stained opaline silica, silicified concretion or oolite in centre. (X 56)



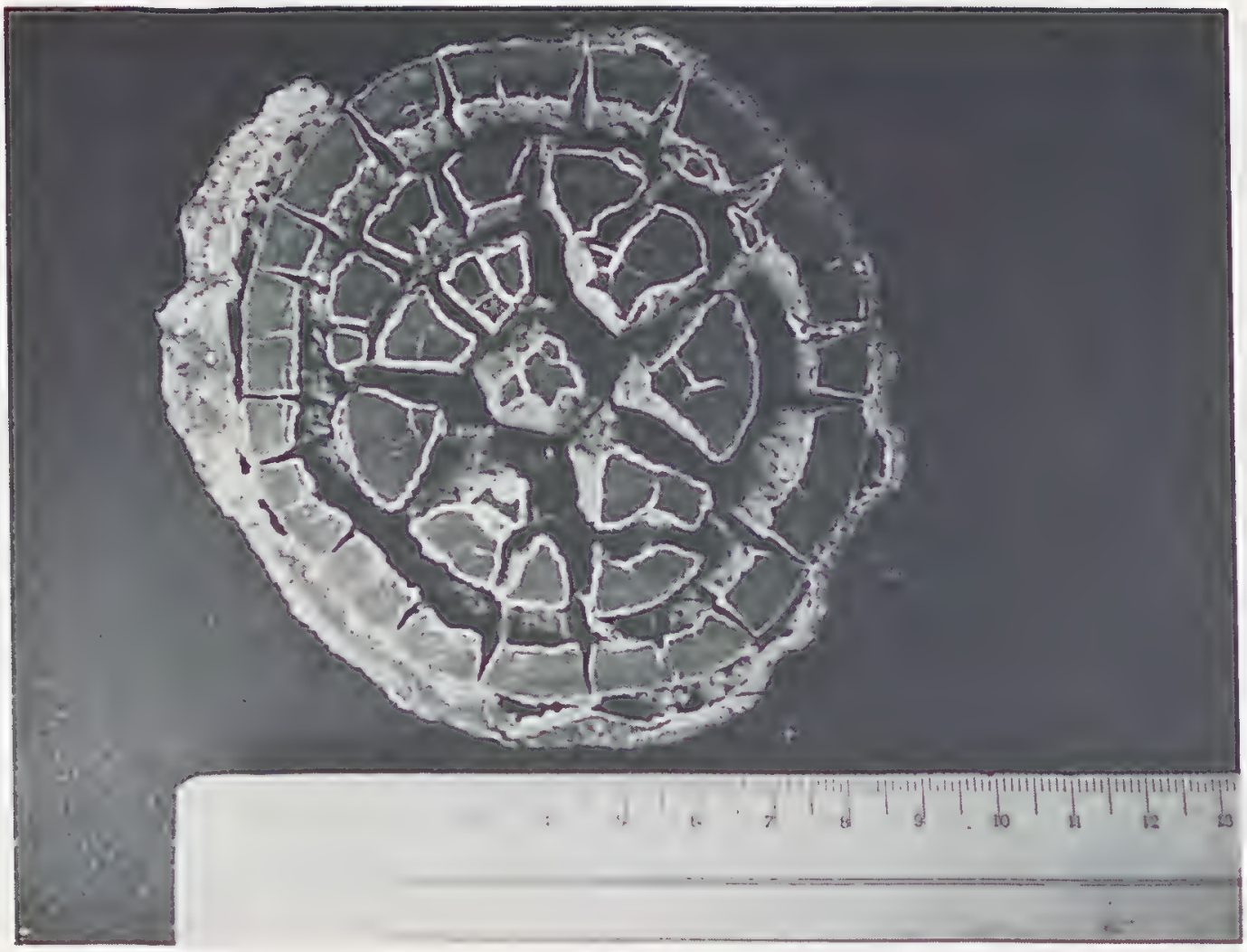
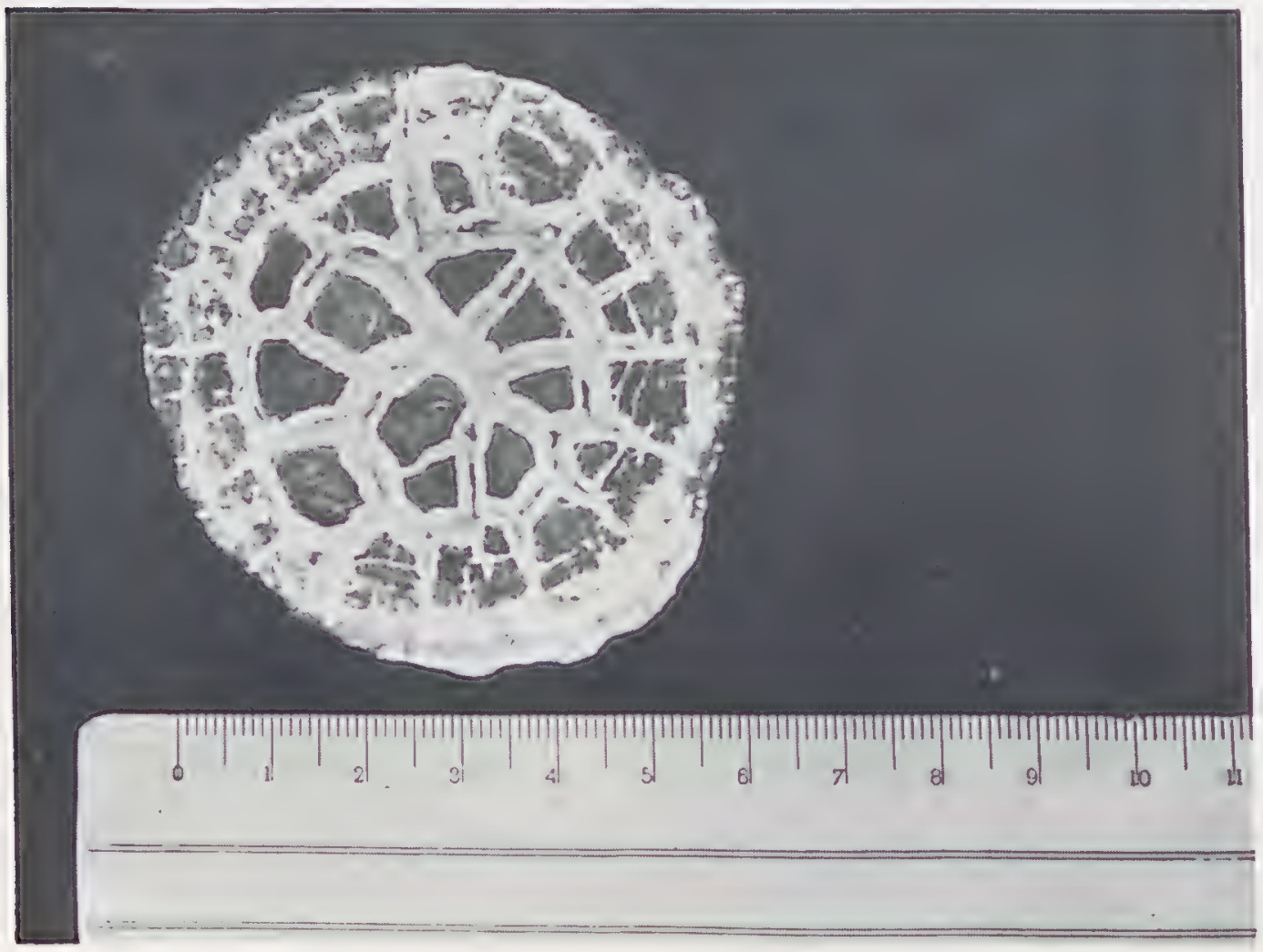


Figure 1.—Section of septarian nodule, Springvale Formation, showing a papery coating of fine quartz crystals coating the syneresis cracks (diameter 9 cm)

Figure 2.—Section of septarian nodule, Springvale Formation, with coarse quartz crystals infilling the syneresis system (diameter 6 cm)



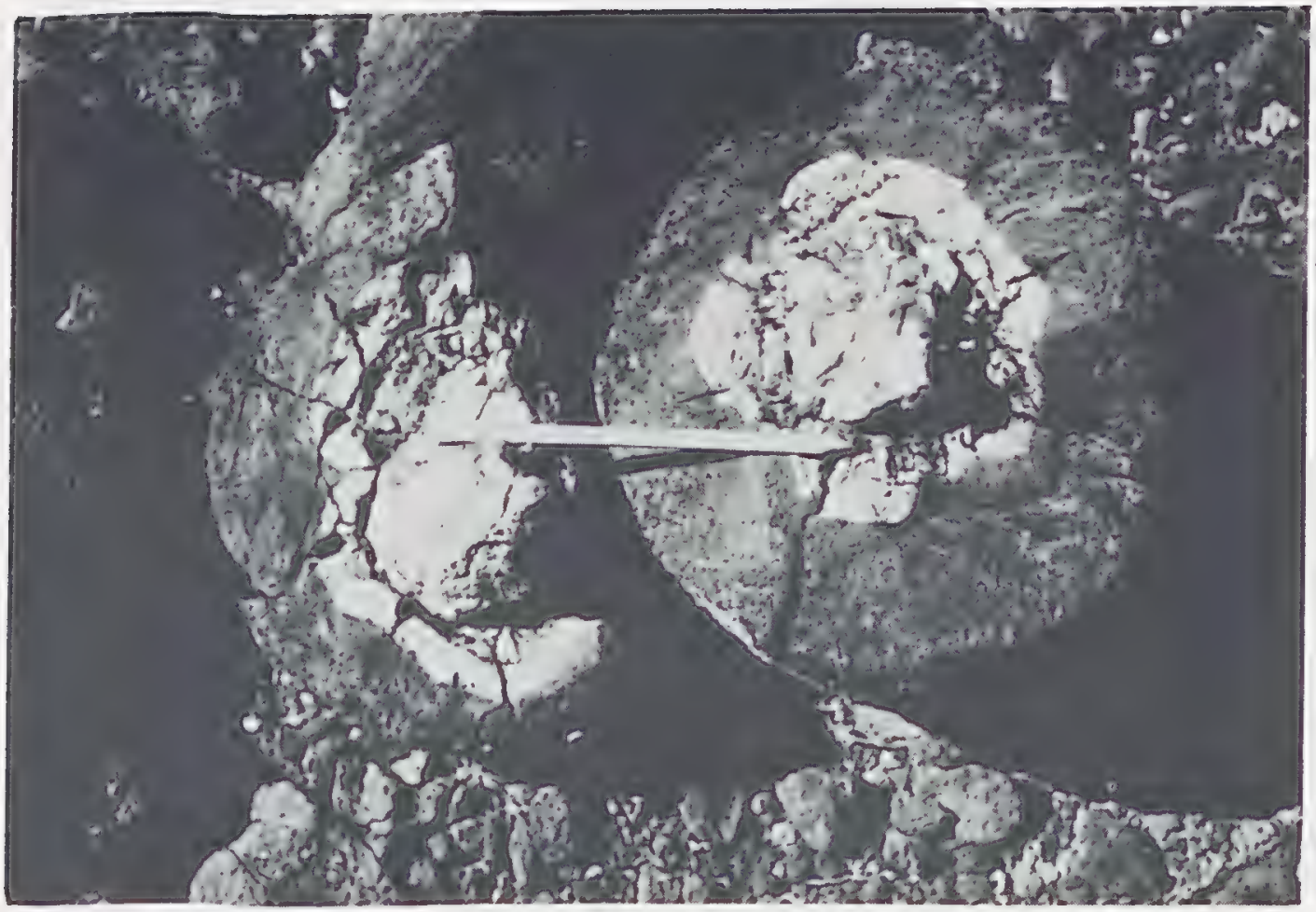


Figure 1.—Ferruginized calcareous concretion, Springvale Formation, showing poorly developed syneresis system. These forms appear to be intermediate in type between solid concretions and septaria

Figure 2.—An example of secondary spherulitic calcite growth in ferruginized limestone from the Springvale Formation. Earlier-formed siliceous concretions (lower right) are cut by the large spherulite (centre). (X 46, plane polarized light)

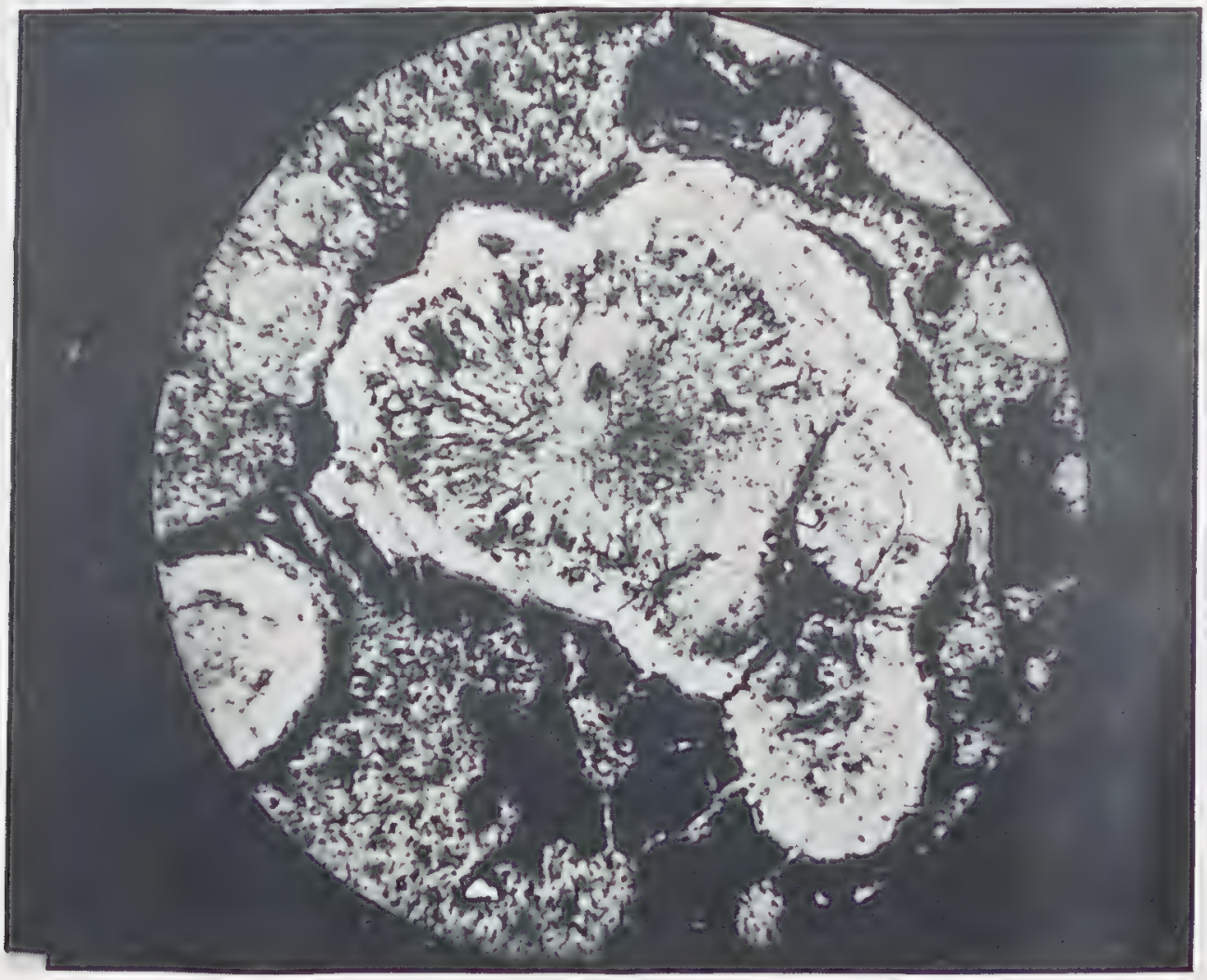


Plate 4

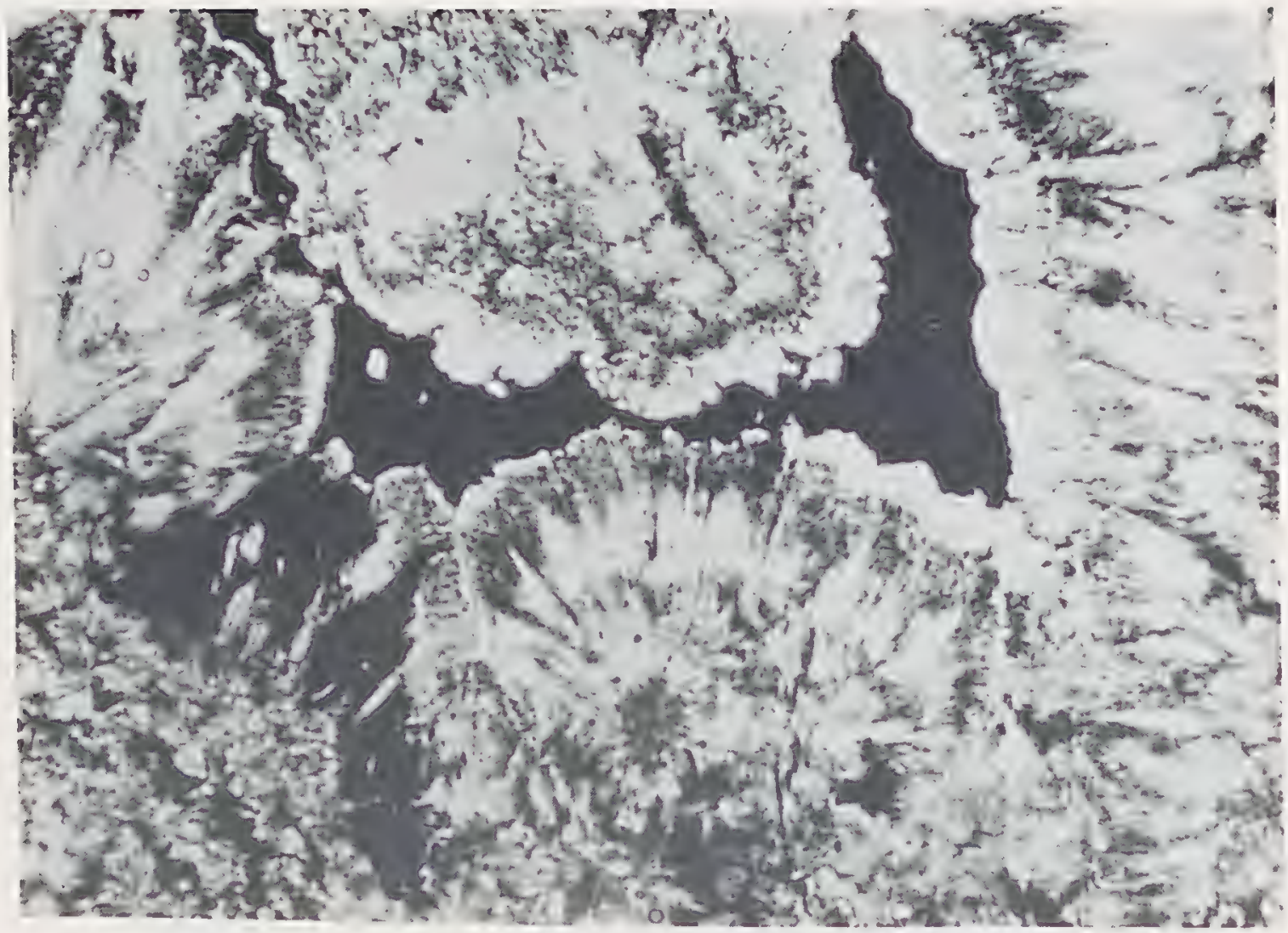


Figure 1.—Later spherultic calcite growth in a ferruginized calcareous concretion from the Springvale Formation. (X 30, plane polarized light)

Figure 2.—Recrystallized ferruginized limestone, Springvale Formation. Iron oxide (dark) mostly confined to intercrystal area (X 105)

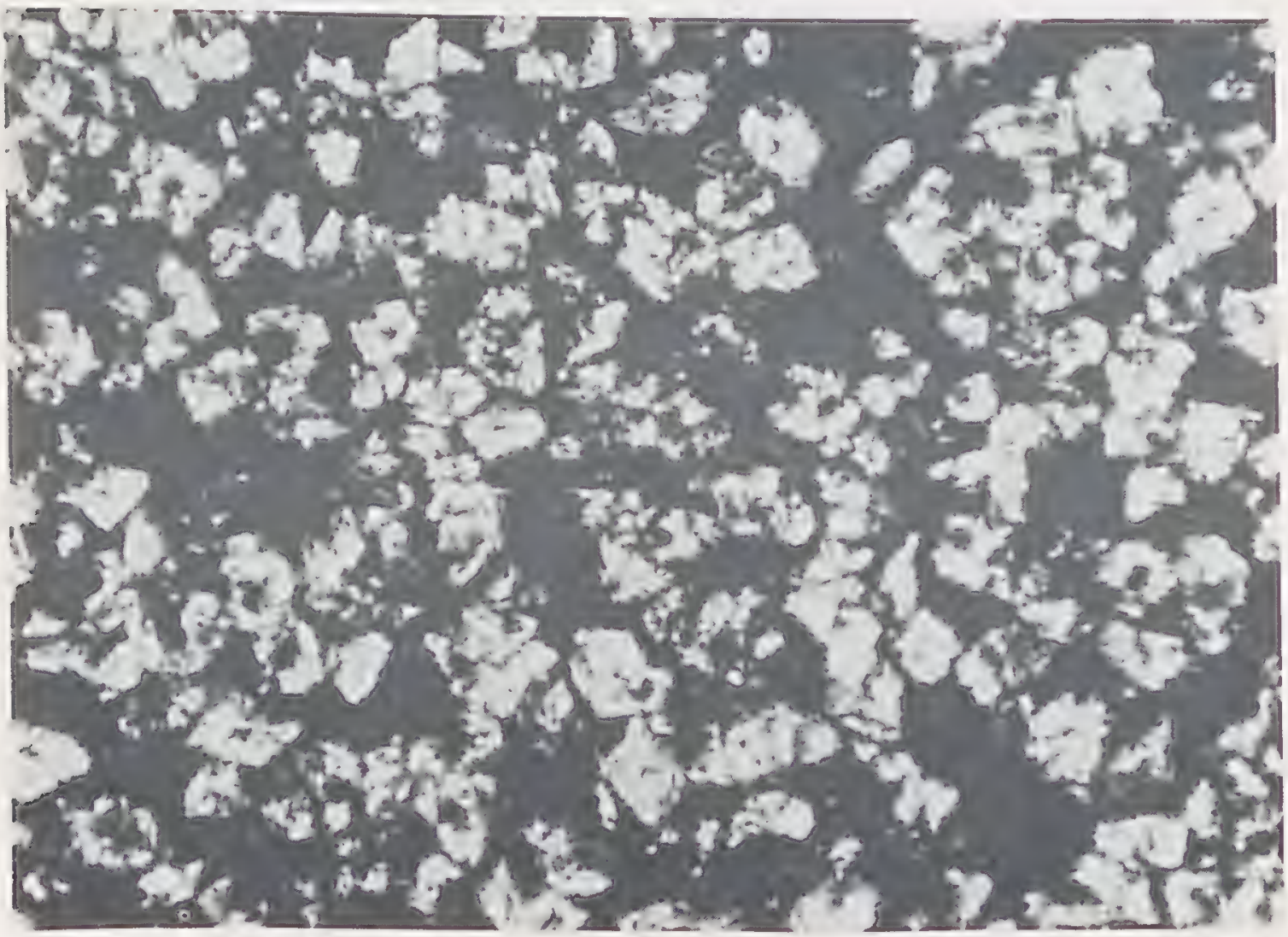


Figure 1.—Type area (S 124) of the Horse Creek Formation showing the thin band of well-bedded argillaceous charophyte limestone (breaking up) in an otherwise poorly stratified limestone section.

Figure 2.—Grey limestone of the Horse Creek Formation overlies ferruginized Springvale Formation in scarp on the west side of the Diamantina River about 5 miles north-west of Hunter's Gorge

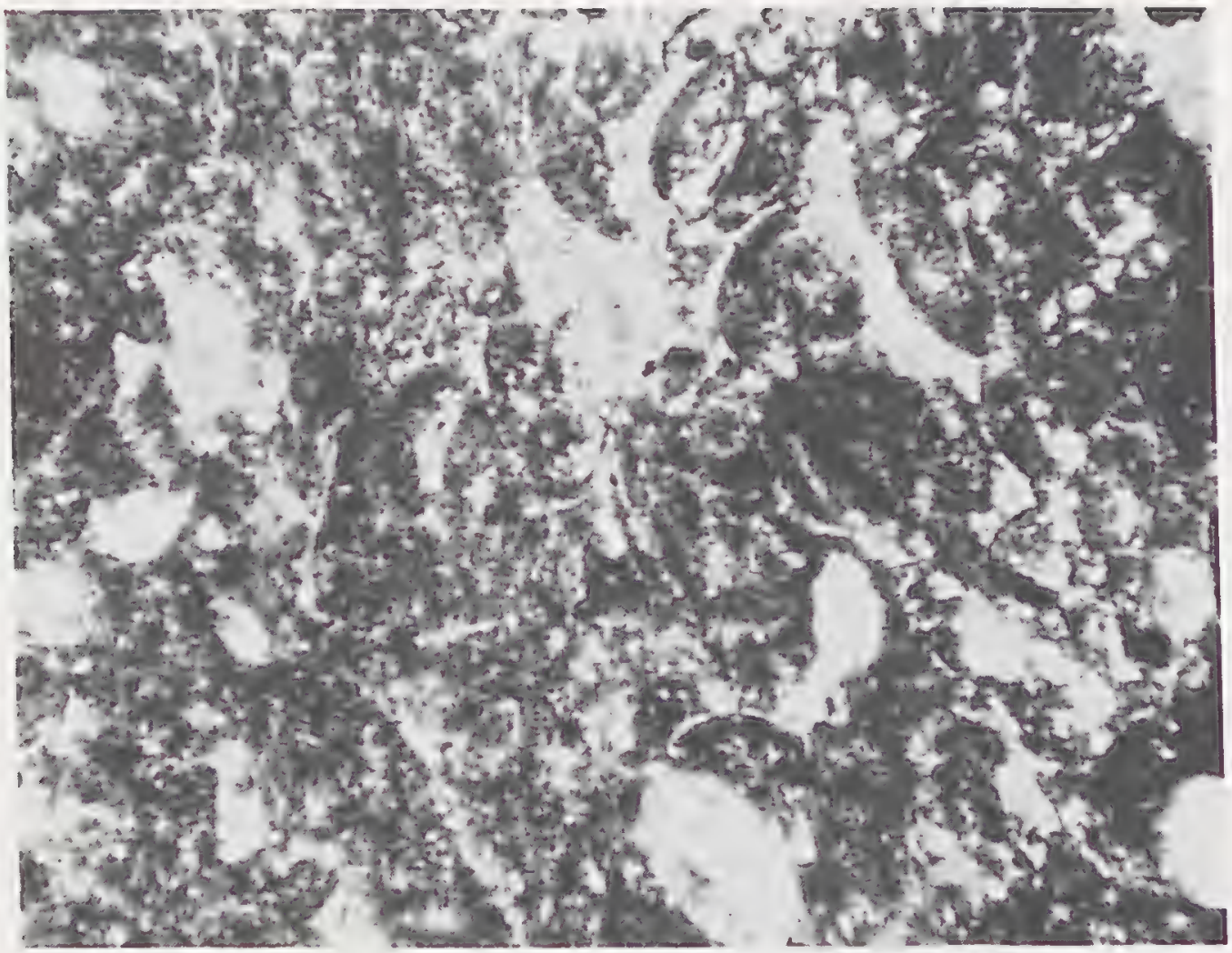


Figure 1.—Lacustrine limestone containing shell remains, Horse Creek Formation. Dark clotted precipitated carbonate with irregular clear recrystallized calcite area. Thin shell fragments are scattered throughout. (X 70)

Figure 2.—Faecal limestone, Horse Creek Formation (X 40)

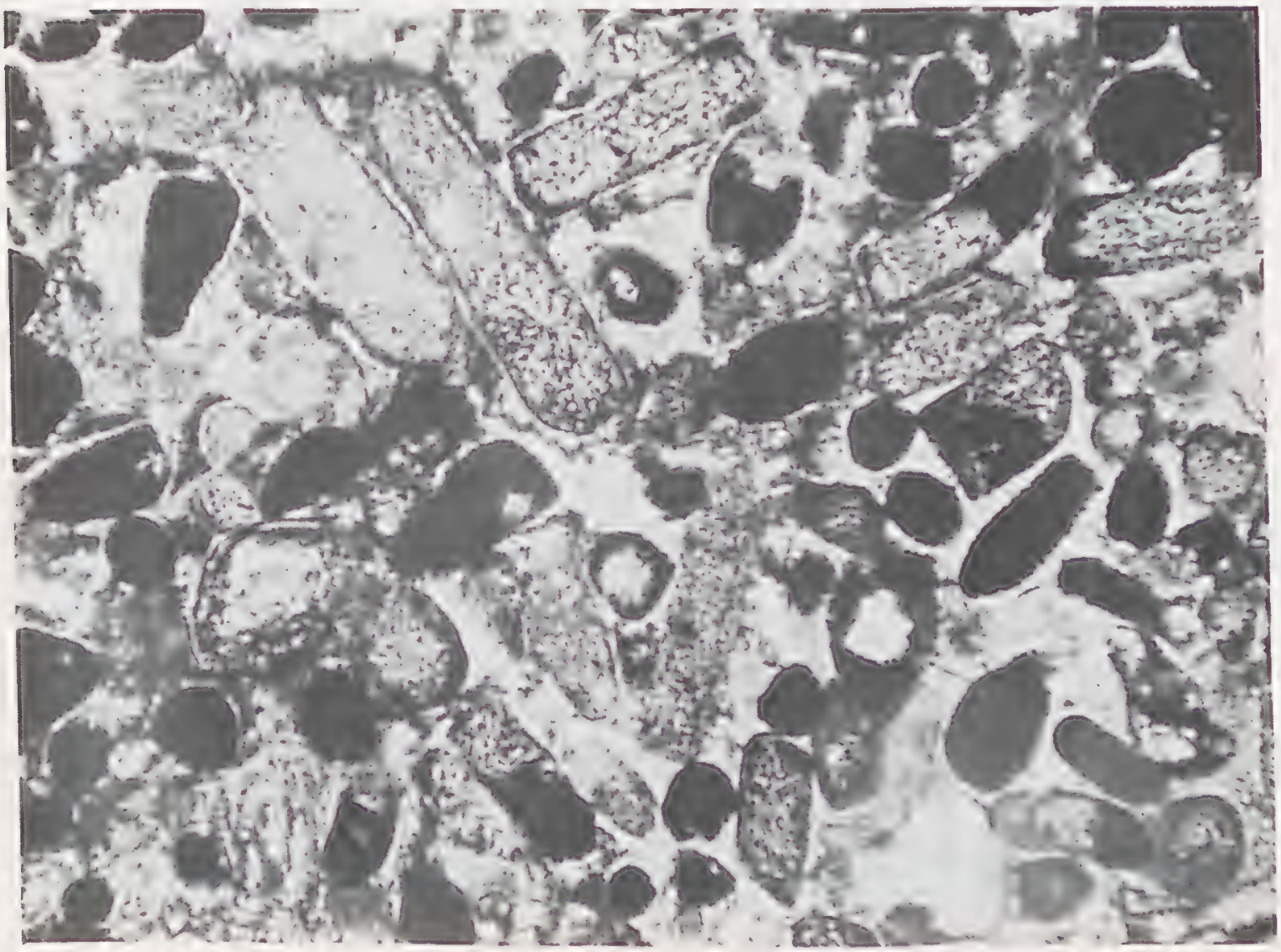


Figure 1.—Partly silicified Marion Formation in blocky outcrop (top) unconformably overlying the finely fractured and indurated lateritized Wilgunya Formation at 12-Mile Mountain

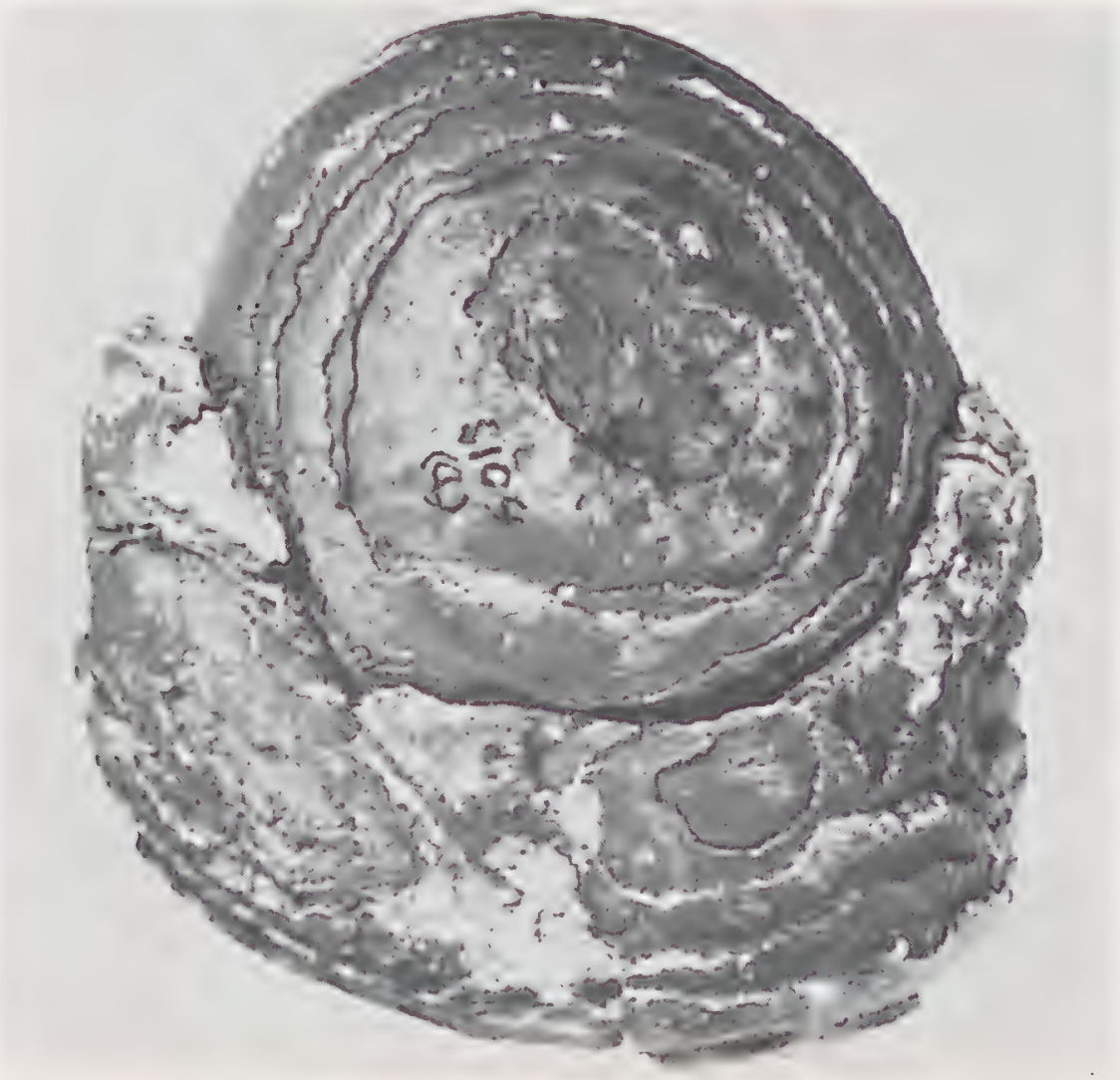
Figure 2.—Austral Downs Limestone, Glenormiston. Massive chalcedony band (central top) overlies partly silicified grey limestone

Figure 1.—Austral Downs Limestone, Glenormiston, showing irregular siliceous replacement of limestone

Figure 2.—Poorly stratified non-siliceous white limestone of the Austral Downs Limestone, Roxburgh Downs

Figure 1.—Silicified Austral Downs Limestone overlies jointed Ordovician dolomite at Lake Wonditti, Glenormiston

Figure 2.—Silicified ?algal colony, Springvale Formation (slightly enlarged)



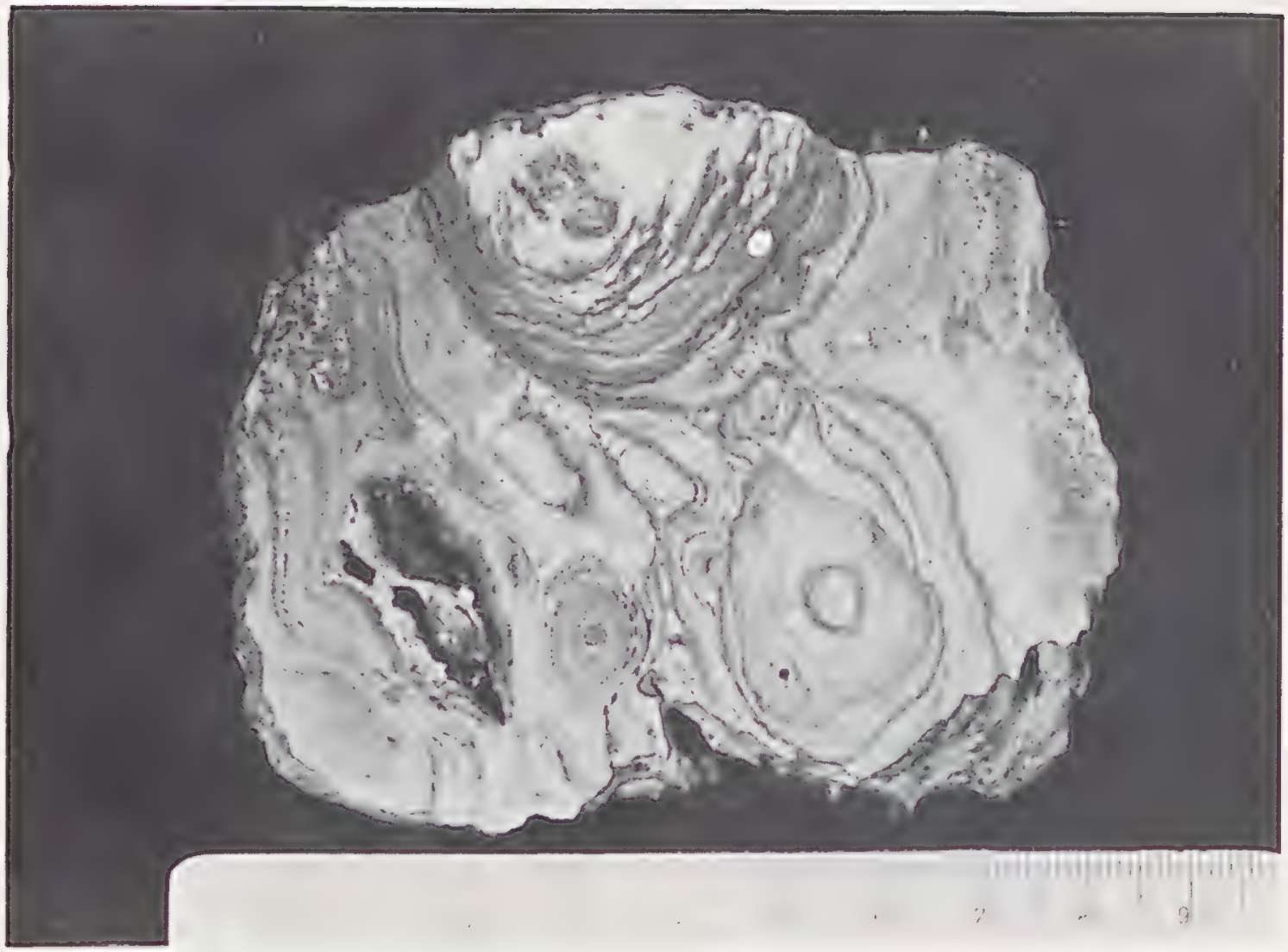
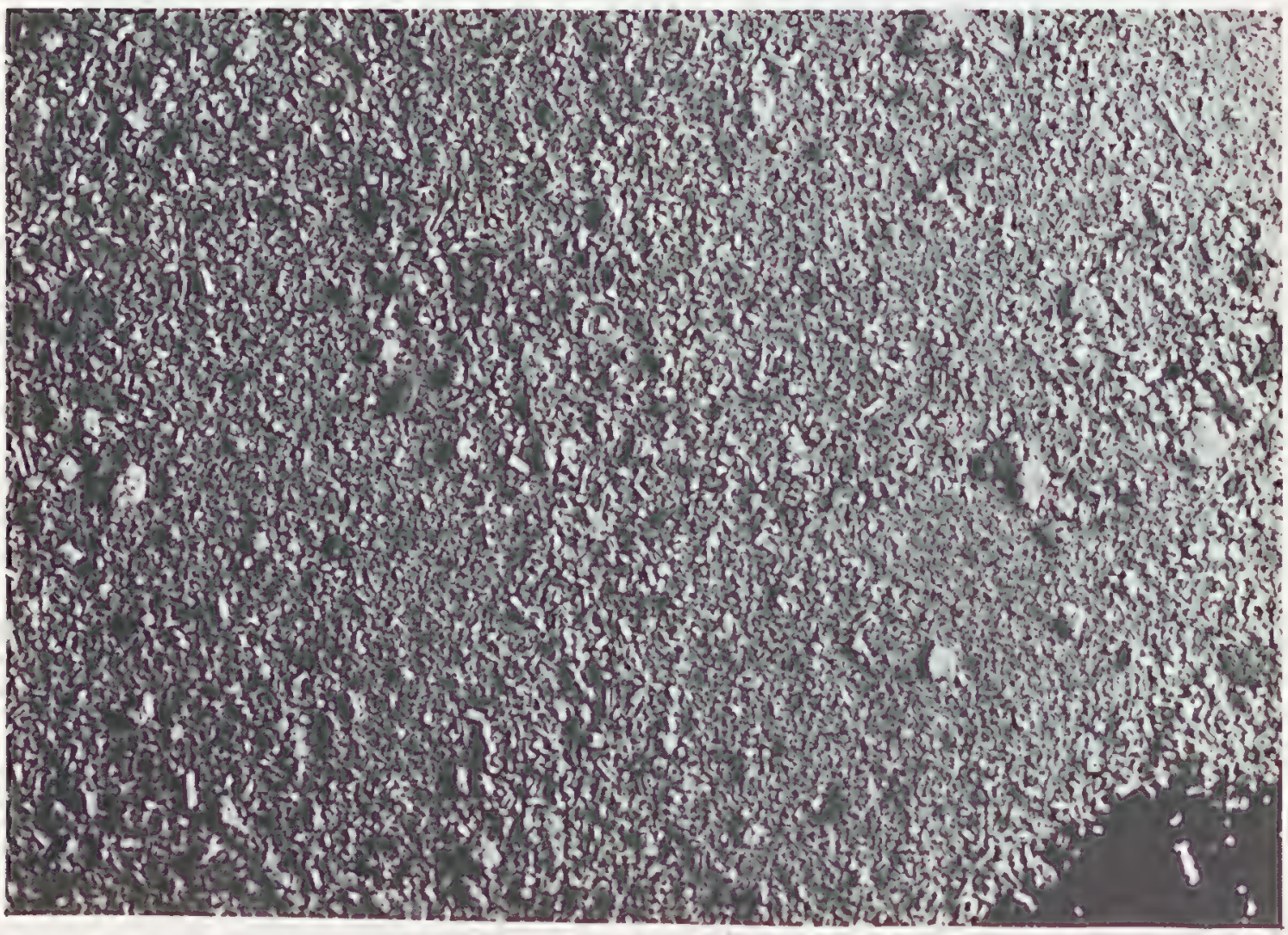


Figure 1.—Algal limestone from locality S 120, Springvale Formation
Figure 2.—Faecal pellets chemically separated from partly silicified faecal limestone of the Horse Creek Formation (X about 10)



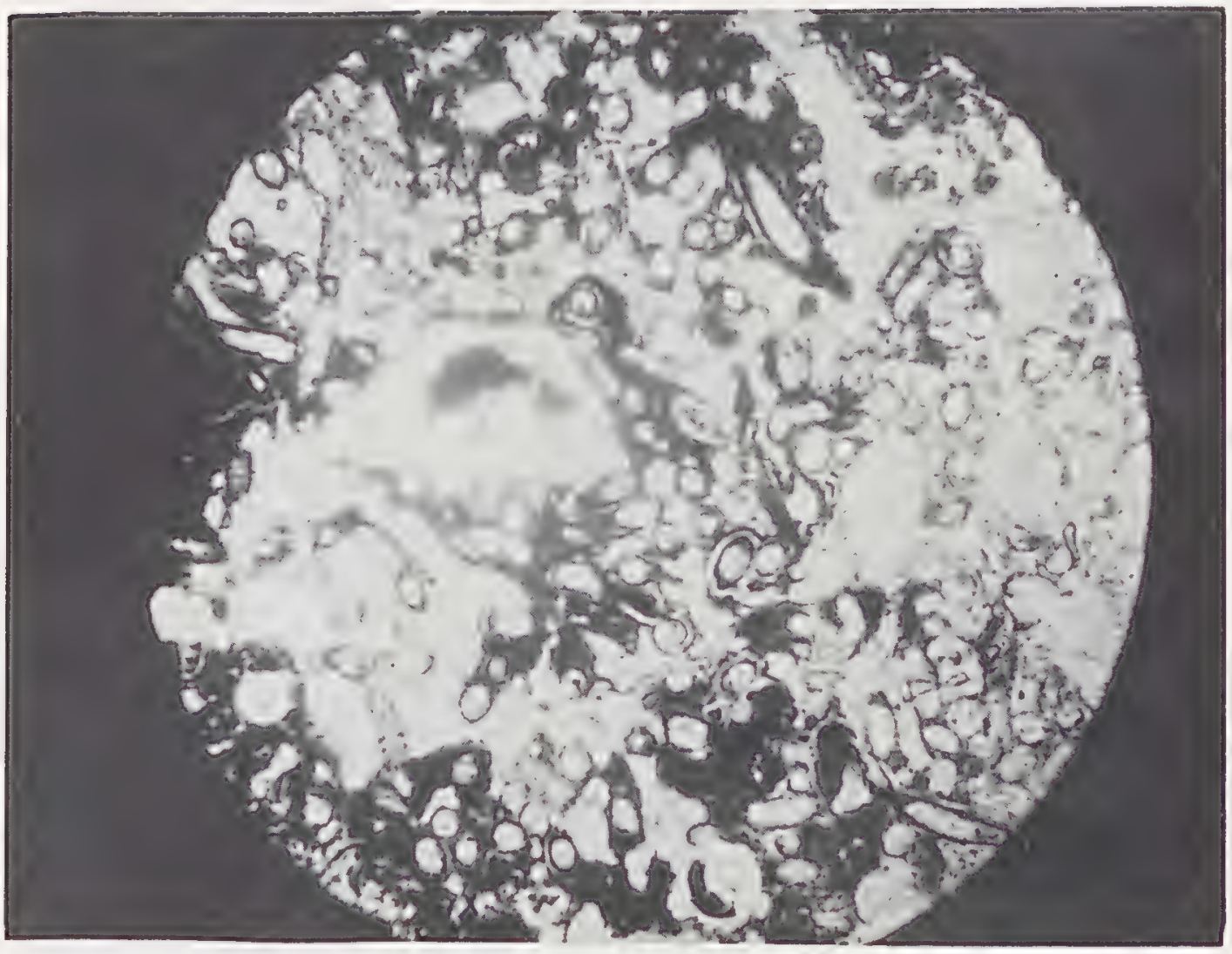


Figure 1.—Probable charophyte stem limestone from a deposit of the Austral Downs type from Aroota Bore, Tobermory, N.T. (X 15)

Figure 2.—Foraminiferal limestone breccia, Austral Downs Limestone from the junction of Manner Creek and the Georgina River, Roxburgh Downs. Foraminifera and ostracode (centre) in fine lime carbonate. (Mag. about X 15)

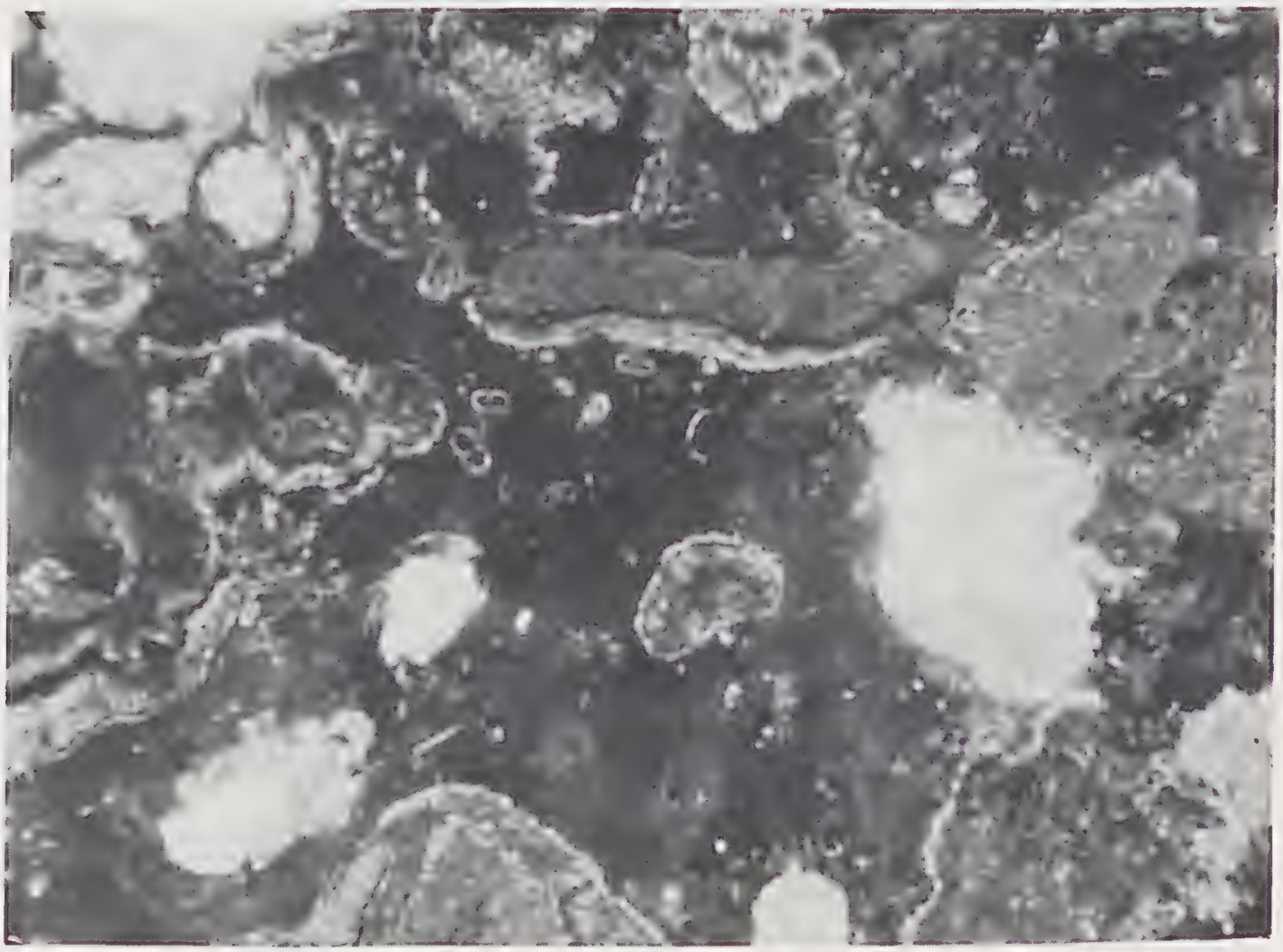
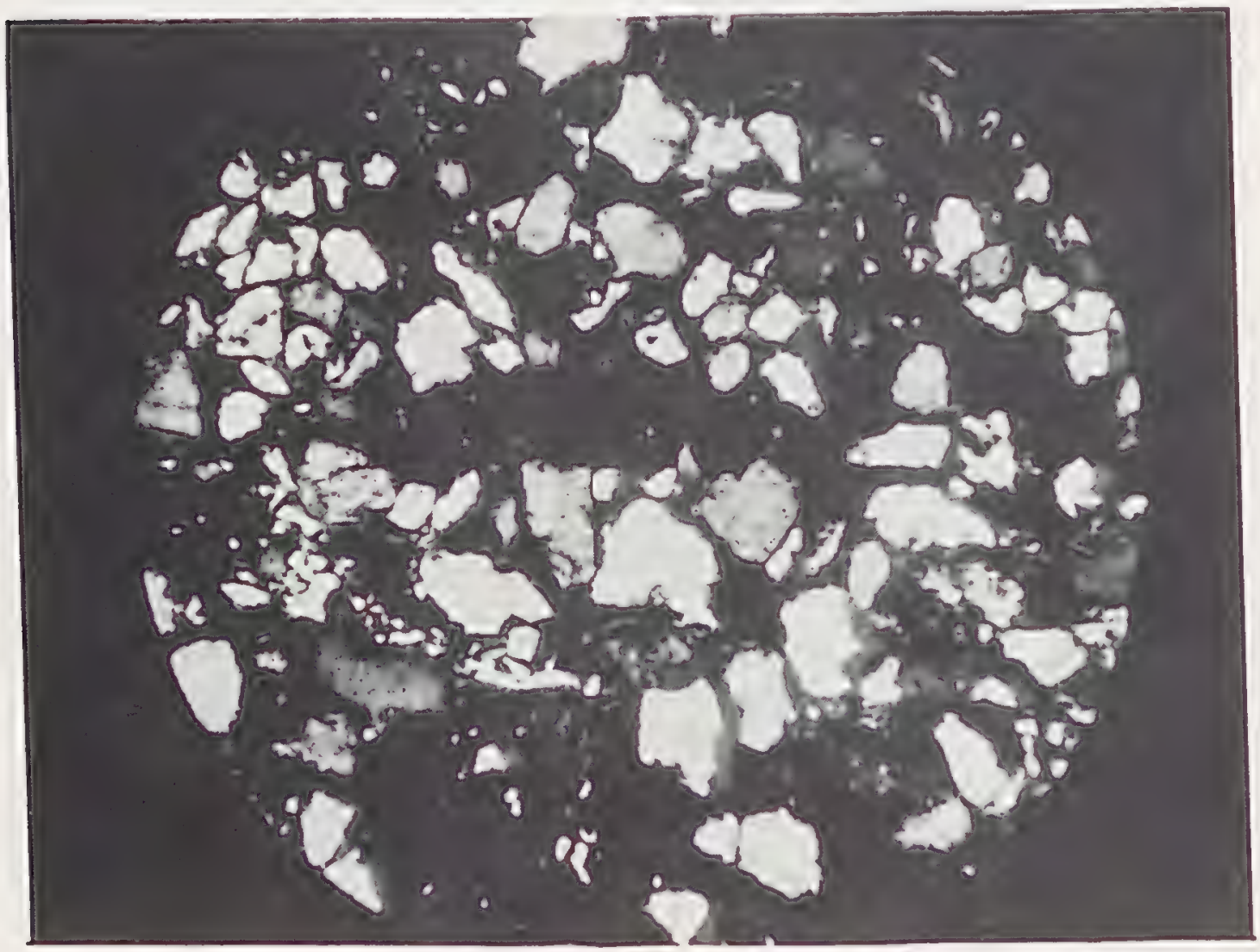
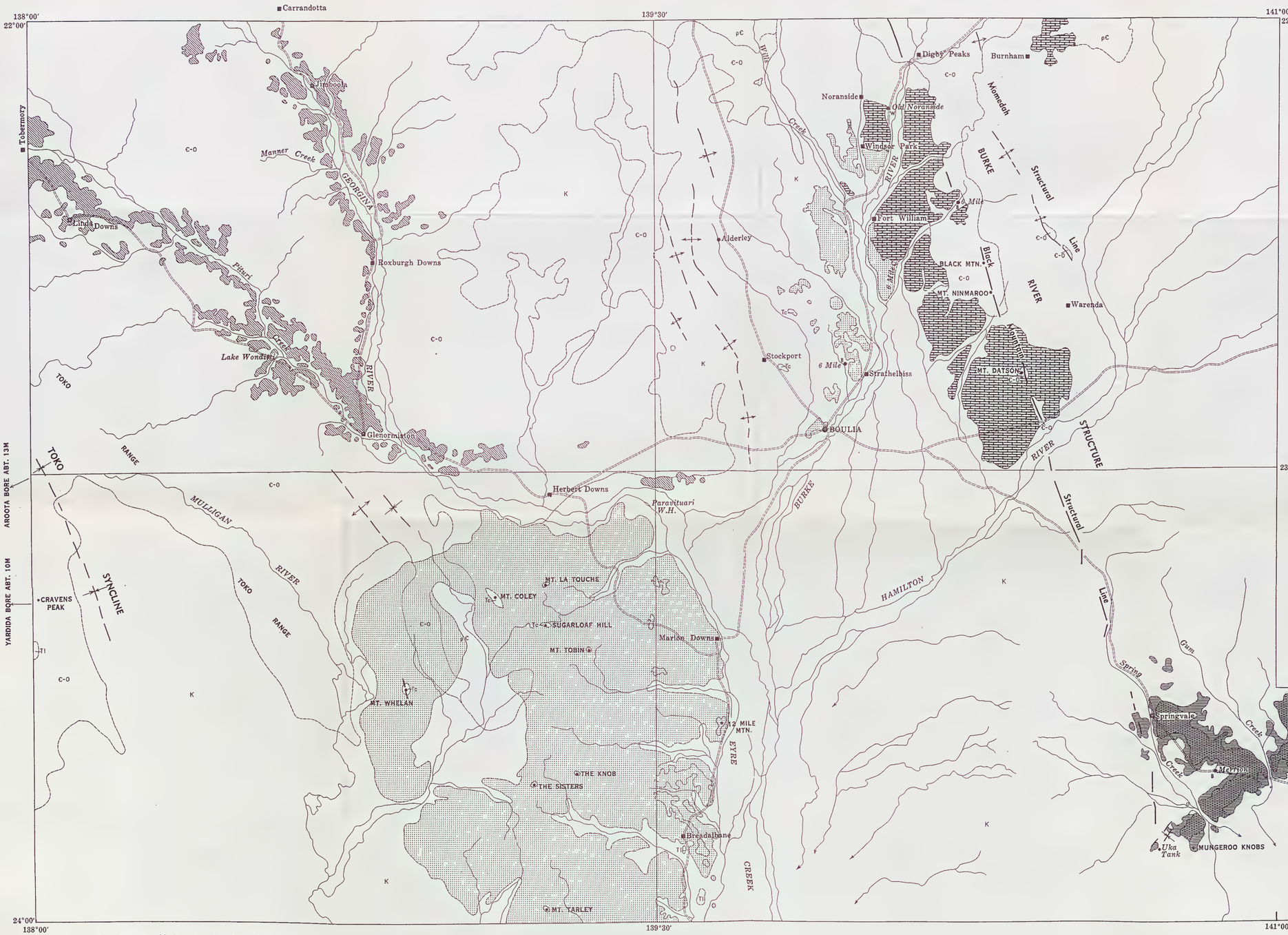


Figure 1.—Columnar billy at the top of the billy profile developed on probable Tertiary sandstone in the Orientos area, South-west Queensland

Figure 2.—Billy, 12-mile Mountain, Marion Formation. Chemically eroded quartz grains (mostly light) set in opaline silica matrix (dark). (X 45, plane polarized light)



TERTIARY GEOLOGY
BOULIA REGION
QUEENSLAND



TERTIARY

Horse Creek Formation		Limestone, common opal
Austral Downs Limestone		Chalcedonic limestone
Noranside Limestone		Chalcedonic limestone
Unnamed limestones	Tl	Chalcedonic limestone
Mt. Coley Sinter	Tc	Siliceous sinter, chalcedony
Marion Formation and derived gibber		Silicified sandstone (solid boundary denotes known Marion Formation outcrop).
Springvale Formation		Silicified limestone, limestone, clay.

CRETACEOUS

	K	Clay, sandstone, rare limestone.

CAMBRIAN–ORDOVICIAN

	C-O	Dominantly carbonate rocks.

PRECAMBRIAN

	pC	Sediments, metamorphics.

- Geological boundary
- Anticline
- Syncline
- Fault

Where position of boundaries and faults is approximate, line is broken; where inferred, queried; where concealed, boundaries are dotted, and faults are shown by short dashes.

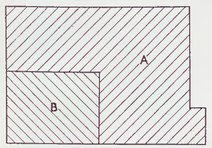
- Road or track
- Township
- Homestead

Geology by: J. N. Casey, M. A. Reynolds, D. B. Dow, P. W. Pritchard, R. R. Vine, K. G. Lucas, R. J. Paten.
Compiled by: R. J. Paten at the Geological Survey of Queensland, May, 1961.
from Bureau of Mineral Resources unpublished geological maps.

Scale
10 Miles to 1 inch

10 0 10 20 30 Miles

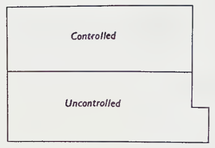
TERTIARY GEOLOGY RELIABILITY



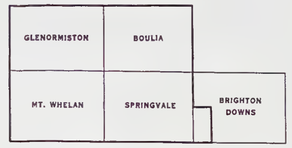
A *Numerous traverses with air-photo interpretation.*

B *Few traverses, detail sketchy*

BASE MAP



INDEX TO 1:250.000 SERIES SHEETS



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QUEENSLAND
DEPARTMENT OF MINES

NATIONAL MUSEUM
29 JUL 1954
OF VICTORIA

GEOLOGICAL SURVEY OF QUEENSLAND
(A. K. Denmead, M.Sc., Chief Government Geologist)

PUBLICATION No. 320

A NEW METEORITE FROM THE GLADSTONE DISTRICT

By N. A. H. SIMMONDS, B.Sc. App. (Geol.), Geologist

RECENT INVESTIGATIONS OF THE TENHAM METEORITE SHOWER

By J. H. BROOKS, B.Sc., Supervising Geologist,
N. A. H. SIMMONDS, B.Sc. App. (Geol.), Geologist
and Miss B. R. HOUSTON, B.Sc. (Hons.), Geologist.

By Authority: S. G. REID, Government Printer
BRISBANE
1964

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FOREWORD

Publication No. 320 is made up of two papers on meteorites of Queensland origin.

Meteorites are comparatively rare in this State and it was therefore surprising when two specimens of very different kinds and from widely separated localities were submitted for identification within a few months of each other.

One of the meteorites, a siderite from Gladstone, was investigated by the late N. A. H. Simmonds, and the other, a stony meteorite belonging to the Tenham meteorite shower, by J. H. Brooks, the late N. A. H. Simmonds and Miss B. R. Houston.

In addition to describing the specimens submitted the authors have gone carefully into the history of these meteorites and they have been able to clear up some uncertainties that existed regarding both the Tenham shower and a previously known iron (Gladstone No. 1) from Gladstone.

It is felt that the papers will make a useful addition to the scanty literature on meteorites in Queensland.

A. K. DENMEAD,
Chief Government Geologist.

A NEW METEORITE FROM THE GLADSTONE DISTRICT

By N. A. H. SIMMONDS, B.Sc. App.(Geol.), Geologist

ABSTRACT

A 53 lb. meteorite found in 1940 about ¾ mile from the site of the 14½ cwt. Gladstone meteorite, is described in detail. It is a coarsest octahedrite containing kamacite, taenite, schreibersite, rhabdite, cohenite, troilite, pyrrhotite, graphite and ?daubreelite.

Additional information is given on the occurrence and mineral composition of the 14½ cwt. Gladstone iron.

The two meteorites are considered to be part of a multiple fall or shower dating from before 1913.

INTRODUCTION

About 1940 Mr. E. Jeffris found a 53 lb. (24·1 kg.) iron meteorite almost completely buried on his property "Woodstock," 4½ miles south of Gladstone (Central Queensland). He gave it to a Mr. Maloney, a man interested in minerals, who kept it in his office in the Commercial Hotel, Gladstone. After Mr. Maloney's death the meteorite remained in the hotel where it was used as a door-stop for many years. A miner, Mr. E. Hopley, recognising the significance of the specimen, generously donated it to the Geological Survey of Queensland museum in February 1959.

Mr. Jeffris was able to show the writer the approximate site of the fall, the co-ordinates of which are 23° 54½′ S., 151° 15½′ E.

This is the second meteorite to be recorded from the Gladstone district, the first was a 14½ cwt. coarsest octahedrite known as the Gladstone meteorite. Some aspects of the discovery of this meteorite will be discussed in a later section. It will be shown that the two meteorites are probably part of a multiple fall, and in this paper the first (14½ cwt.) mass is referred to as the Gladstone No. 1. It is proposed to name the new meteorite the Gladstone No. 2.

Other meteorites recorded from Queensland (Map 1) are the Ellerslie, an aerolite weighing 22½ lb. (10·17 kg.); the Glenormiston, a brecciated medium octahedrite weighing 90 lb. (about 40 kg.); the Mungindi Nos. 1 and 2, finest octahedrites weighing 62 lb. (28·12 kg.) and 51 lb. (23·13 kg.) respectively; the Tenham stones, enstatite olivine chondrites, part of a meteorite shower of which 290 representatives are known; the Thunda meteorite, a medium octahedrite weighing 137 lb. (62·13 kg.), and the South Queensland iron, a coarse octahedrite of doubtful origin represented by one fragment weighing 72 grams.

The writer gratefully acknowledges the information and assistance received from Messrs. E. Jeffris, W. Golding, Jim Fisher, Jack Fisher, L. Lee and N. Nott. Thanks are due to the manager of Swift & Co. meatworks for permission to search on "Woodstock" station, and to the *Gladstone Observer* for publishing an article on the Gladstone meteorites prior to the field investigation. The writer is also indebted to Mr. G. Mack, Director of the Queensland Museum, for casts prepared of the Gladstone No. 2 and for the loan of a slice of the Gladstone No. 1 for examination, to Dr. G. Baker and Mr. R. O. Chalmers for useful information, and to Dr. H. H. Nininger for helpful discussions.

FIELD INVESTIGATIONS

A total of 14 days was spent in the Gladstone district making enquiries and searching for more specimens. The finder of the No. 2 iron, Mr. E. Jeffris, indicated the site of the fall. This was about ¾ mile south of the site of the Gladstone No. 1 on a rocky quartzite ridge trending north-south (Map 2). Mr. Jeffris stated that two more meteorites had been collected from this ridge and another had been seen by his son many years ago.

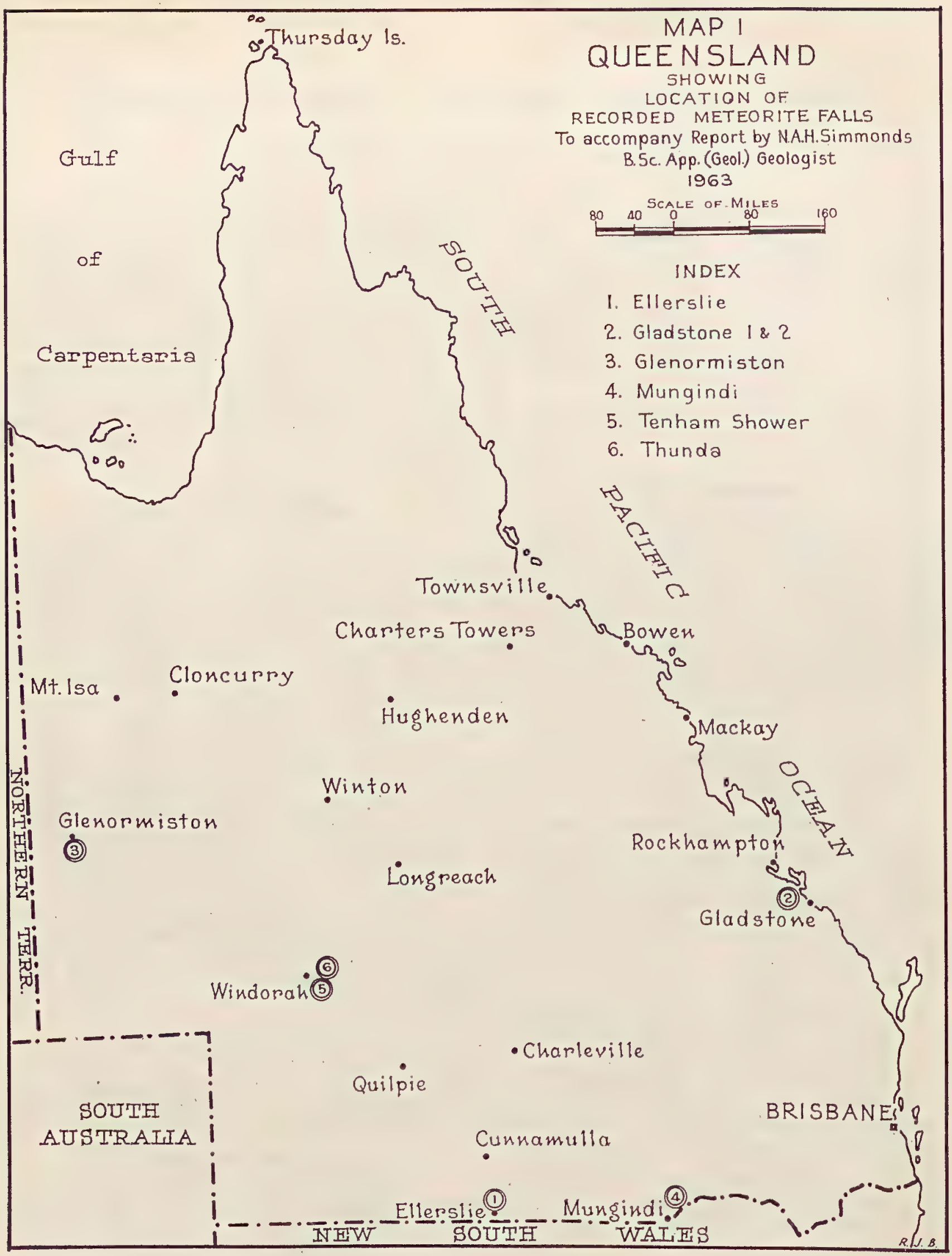
Of the two that had been collected, one (reported to be pear shaped and weighing 20–30 lb.) had been taken to the Commercial Hotel and kept with the Gladstone No. 2. This information was confirmed by several other people but the meteorite disappeared several years ago and nothing could be learnt of its present whereabouts. Some claimed it had been sent to a museum but they may have been referring to the Gladstone No. 2.

The other meteorite was taken to the homestead and left with a number of other rocks. No sign of this iron could be found and it is possible it was used with other rocks and rubbish by a subsequent owner of "Woodstock" to fill a deep gutter near the homestead.

An unsuccessful systematic search for more specimens was conducted along the ridge. Where the terrain and vegetation permitted, an Army mine detector was used, the rough steep hillside and vine covered areas being searched visually.

GLADSTONE No. 1

Very little information concerning this meteorite has been published. It was briefly described with analyses in Richards (1930). An interesting point in some of the published records is the association of


MAP I
QUEENSLAND
SHOWING
LOCATION OF
RECORDED METEORITE FALLS
To accompany Report by N.A.H.Simmonds
B.Sc. App. (Geol.) Geologist
1963
SCALE OF MILES
80 40 0 80 160
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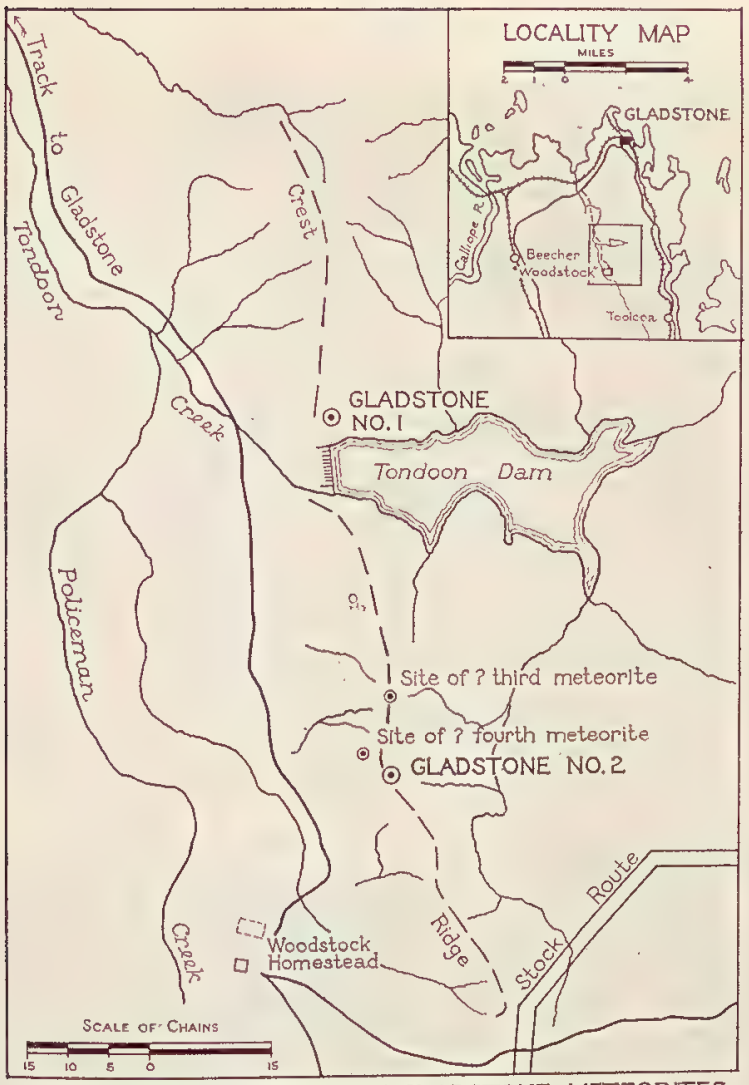
1. Ellerslie
2. Gladstone 1 & 2
3. Glenormiston
4. Mungindi
5. Tenham Shower
6. Thunda
Thursday Is.
Gulf
of
Carpentaria
SOUTH
PACIFIC
OCEAN
Townsville
Charters Towers
Bowen
Mt. Isa
Cloncurry
Hughenden
Mackay
Winton
Glenormiston
Rockhampton
Longreach
Gladstone
NORTHERN TERR.
Windorah
Charleville
Quilpie
SOUTH
AUSTRALIA
BRISBANE
Cunnamulla
Ellerslie
Mungindi
NEW SOUTH WALES
R.J.B.



MAP 2 SHOWING LOCATION OF GLADSTONE METEORITES

the Gladstone No. 1 with the South Queensland Meteorite, a coarse octahedrite which was listed in the Ward and Coonly 1904 Catalogue as being found in 1894.

With reference to the South Queensland iron, Richards (1930) writes: "As the only meteorite of this type known in Queensland is the Gladstone meteorite, and as part of this has been missing for many years it is possible that this represents the missing portion".

Hodge-Smith (1939) writes: "In regard to the South Queensland iron it would appear that it is portion of the Gladstone iron, . . . in 1925 Wards purchased the main mass of the Gladstone from Mr. Dunstan in whose possession it probably was in 1904". He gives the year of discovery of the Gladstone as 1894.

The following information pertaining to the Gladstone No. 1 was obtained from close relatives and friends of the men (now deceased) directly involved in its discovery.

The Gladstone No. 1 was found in 1912 or 1913 by a Mr. Tim Lee, a surveyor's assistant at the time, during the survey and construction of a dam on Tondoon Creek, 4 miles south of Gladstone (Map 2). The meteorite was partly buried close to the present site of the retaining wall and on the southern slope of a large hill. The co-ordinates of this site are 23° 54′ S, 151° 15½′E. The discovery was reported to the Town Clerk, Mr. A. Fisher, who visited the area and apparently recognised the meteoritic character of the iron. At least one piece was broken off with an axe and retained by Mr. Fisher. After some considerable effort the meteorite was conveyed to Gladstone by horse and dray.

Subsequently, it was taken to Brisbane, stored in the Geological Survey bulk store, displayed in the State Mineral Exhibit at the Brisbane Show in August 1926 (*Qld Govt Min. J.*, 1926), and finally sold by Mr. B. Dunstan, Chief Government Geologist, to Wards' Natural History Establishment about 1929. In 1953 the main mass was in the Field Museum of Natural History, Chicago (Prior, 1953).

With regard to the piece removed at Gladstone, Mr. Jack Fisher, a son of the former Town Clerk, stated that the piece in his father's possession, or part of it, was taken to a blacksmith's forge, and that a couple of rings had been made from it. The present whereabouts of the rings or any remaining iron is not known.

It is the writer's opinion that there can be no correlation of the Gladstone No. 1 and South Queensland meteorites. The South Queensland is a coarse octahedrite known before 1904; the Gladstone No. 1 is a coarsest octahedrite not known before 1912, and certainly not in Dunstan's possession in 1904. The missing piece of the Gladstone No. 1 referred to by Richards is probably that portion retained by Mr. A. Fisher when the meteorite was discovered.

A small slice (measuring approximately 4 x 1½ in.) of the Gladstone No. 1 meteorite was obtained from the Queensland Museum for etching and macro-examination. The width of the kamacite bands range from 3 to 11 mm. with an average of 4 mm. Very narrow and discontinuous taenite lamellae lie between the kamacite plates. The iron is speckled with rhabdites except in proximity to schreibersite bodies, and small cohenite inclusions parallel the widmanstatten texture (Plate 3, fig. 1).

Unfortunately no nodular material was available for examination. The following incomplete description was given in Richards (1930). "Apparently there is a mixture of coarse troilite (crystals), graphite and particles of iron in the nodules". The "particles of iron" may well be schreibersite and/or cohenite. An analysis of a nodule did not include figures for carbon or phosphorus (Table 1, Column 4).

GLADSTONE No. 2

External Features

The meteorite is roughly square in shape, with sides of approximately 9 in. and a maximum thickness of 4 in. (Plates 1 and 2). The meteorite provides an excellent example of surface features producing during flight.

The front face (Plate 1, fig. 1) is convex with the corners, one in particular, turned slightly back (Plate 2, fig. 1). About 30 pits can be seen ranging in size up to 2 in. across and ½ in. deep. Several graphitic nodules are in evidence, the largest, on one edge of the iron, being approximately 2 in. long and ½ in. in diameter.

Two sides are developed and two edges are formed where front and rear faces wedge together.

The rear face (Plate 1, fig. 2) consists of two large concave surfaces joined in a sharp diagonal ridge. These surfaces measure approximately 9 x 9 x 12 in. and 9 x 8 x 12 in. and have maximum depth of 1 in. and ½ in. respectively. A deep pit on the larger of these surfaces may represent a burnt-out nodule.

The meteorite has a thin oxide crust; no flow lines are to be seen.

Preparation for Examination

A small slice was cut from one corner of the meteorite for determination purposes. An excellent plaster cast was then prepared and painted by officers of the Queensland Museum, thus preserving the external features. The small slice resulted in 4 small fragments which were polished for micro-examination. A large nodule near a corner of one of the polished faces was removed and polished for microscopic examination.

A major slice was made at the Department of Mines Drilling Branch workshops using a new "Avon" high speed steel blade. Since the shavings were to be collected for analysis the machine was carefully cleaned of grease and other shavings prior to use and no coolant was used. There was very little wear on the blade and no teeth were lost. Although the meteorite became fairly hot during the operation, the heat developed was considered insufficient to substantially alter the structure of the iron.

The sawn faces were machined flat at the University of Queensland, Department of Mechanical Engineering, and finally polished by hand with wet carborundum paper.

The weights of the two portions after cutting and polishing were 38 lb. 14 oz. (17·65 kg.) and 12 lb. 10 oz. (5·74 kg.) the area of each of the polished surfaces being approximately 22 sq. in. One of these faces was preserved in the polished state and the other was etched with 5% Nital to reveal the macrotexture.

Specific Gravity

The specific gravity of the whole meteorite was determined as 7·7; values for three of the small slices were 7·65, 7·80 and 7·61 respectively.

Chemical Composition

Two chemical analyses were made at the Queensland Government Chemical Laboratory.

The first analysis (Table 1, Column 1) was made of the shavings collected from the first cut across one corner of the iron. This cut exposed an elongate schreibersite-cohenite-graphite body but no other major inclusions. The analyst reported that the low total was due, at least in part, to oxidation of the material before analysis.

The second analysis (Table 1, Column 2) was made from a carefully quartered sample of shavings collected from the major cutting operation. This sample included material from ten nodules, ranging from 2 to 14 mm. in diameter, and several veins.

TABLE 1

COMPARISON OF ANALYSES OF GLADSTONE NO. 1 AND NO. 2

—	Gladstone No. 2 (1)	Gladstone No. 2 (2)	Gladstone No. 1 (iron)	Gladstone No. 1 (nodule)
Fe	91·59	91·95	92·9	59·4
Ni	6·57	6·70	6·4	2·0
Co	0·53	0·47	0·01	0·3
P	0·38	0·27	0·18	no det^n
S	nil	0·04	nil	33·4
C	0·18	0·27	nil	no det^n
Cu	nil	0·02	no det^n	no det^n
Cr	nil	nil	no det^n	no det^n
Cl	nil	faint trace	no det^n	no det^n
Si	nil	0·06	no det^n	no det^n
Mn	nil	nil	no det^n	no det^n
Residue	..	..	..	2·3
TOTALS	99·25	99·78	99·49	97·4
Fe/NiCo	12·9	12·8	14·5	

(1) Analyst K. H. Deasy
(2) Analyst K. H. Deasy & C. H. Cooper
Gladstone No. 1— Analyst F. Connah (Richards, 1930)

Macro-examination

Etching one of the polished faces with 5% Nital brought out a moderately developed widmanstatten texture (Plate 2, fig. 2). The kamacite bands are rarely less than 3 mm. in width and range up to 10 mm. The average width is about 4 mm. On this basis the meteorite can be classified as a coarsest octahedrite.

The kamacite lamellae are separated by thin discontinuous plates of taenite, and plessite fields occur at the junction of different kamacite bodies. Taenite and plessite appear to be more abundant toward the tail of the section.

Two types of inclusions, veins and nodules, can be seen on the section. The veins appear to be of cohenite and a mixture of cohenite, schreibersite and sulphide. The cohenite veins parallel the widmanstatten texture while the more complex type is unrelated to the texture but appears to join two of the nodules. The nodules consist predominantly of graphite and pyrrhotite, with narrow rims of cohenite and schreibersite; only one is enclosed in swathing kamacite. Troilite was detected in six of the nodules by sulphur printing.

Micro-examination

Iron. Mineragraphic examination of the small slices revealed that the iron consists predominantly of kamacite with lesser amounts of phosphides, taenite and cohenite.

The *kamacite* is tin white, isotropic, easily scratched with a steel needle and magnetic. It is readily attacked by HNO_3 and Nital, and slowly attacked by Picral.

The *taenite* on an unetched surface is difficult to distinguish from kamacite. It is softer, ductile and magnetic but is not affected by the usual etching reagents. Taenite forms narrow plates, often discontinuous in section, between the kamacite bodies.

At the junctions of kamacite plates, *plessite* and *dense plessite* are often present.

Two iron nickel phosphides, *schreibersite* and *rhabdite,* are present. The schreibersite occurs as small, irregular-shaped bodies and veins in the kamacite. On a freshly polished surface it is difficult to distinguish from the iron, but it weathers to a pale brownish colour. It is anisotropic, hard, brittle, very often pitted, and cannot be scratched with a steel needle. The schreibersite is negative to all standard etching reagents except HNO_3 (slow effervescence) and KOH, which turns it brown. It does not deposit copper from dilute $CuSO_4$.

The rahbdites occur as small, euhedral and subhedral, prismatic crystals, usually with one or two preferred directions. They have a similar colour to the schreibersite, and are anisotropic, hard, magnetic, and inert to standard etch solutions. They do not deposit copper from dilute $CuSO_4$. The iron is fairly rich in this phosphide which occurs in all sizes from a micron or so to a millimeter in length. In proximity to the schreibersite veins and bodies, the iron is free of rhabdites and they are absent in the swathing kamacite of the nodule examined.

Compound Vein. A vein of schreibersite, cohenite and graphite is exposed in one of the small slices. This ranges in width from 0·2 to 2 mm. and consists of an incomplete central zone of graphite surrounded by cohenite and swathing schreibersite. The *graphite* is crystalline, light grey in colour, distinctly pleochroic, anisotropic, and very soft.

The *cohenite* is a pale grey colour, harder than the schreibersite and isotropic. It appears to be inert to the standard etch reagents but deposited copper from a weak $CuSO_4$ solution. Attempts to confirm this identification with boiling picrate solutions (as described by Perry, 1944) gave inconsistent results, but electrolytic etching with alkaline sodium picrate darkened the mineral without affecting the adjacent schreibersite.

In section, the swathing schreibersite forms a narrow incomplete rim about the cohenite. The rim appears to have optical continuity.

Nodule. The nodule has a rather complex composition. In polished section it was found to consist of a core of pyrrhotite and a pyrrhotite-graphite mixture, surrounded by a zone, up to 1 mm. wide, made up of thin rims of troilite, graphite, cohenite and schreibersite. The whole nodule is enclosed in swathing kamacite.

The *pyrrhotite* is a pinkish brown colour, it can be scratched with a steel needle and is distinctly anisotropic in blues and browns. Dilute HNO_3 and boiling sodium picrate solutions bring out a grain structure and what appears to be a marked cleavage.

The *graphite* associated with the pyrrhotite is very finely crystalline, and occurs as connected and isolated aggregates in larger, optically continuous grains of pyrrhotite.

The *troilite* is similar to the pyrrhotite except in etch reactions. HNO_3 causes rapid effervescence and the liberation of H_2S. It occurs in grains up to 0·7 mm. with some minor alteration to marcasite along fractures. The associated graphite occurs in larger grains than in the core.

The *cohenite* and *schreibersite* rims are of variable thickness with small veins of cohenite often extending into the outer rim of schreibersite.

Iron oxide occurs between the schreibersite and swathing kamacite, extensively replacing the latter, and veining the schreibersite with only minor replacement. The troilite is also replaced by iron oxide to some extent.

?Daubreelite. The etch pattern formed on the sulphides by HNO_3 and boiling sodium picrate solutions appears under low magnification as minute parallel cleavages. On closer inspection with higher power (x 950) they are seen to be strings of minute blebs of a grey mineral up to 0·003 mm. wide. A few larger areas up to 0·02 mm. wide were found associated with the strings or as isolated grains with smooth outlines. The mineral appears to be isotropic. Its hardness determined by the bright line method on an unetched surface is greater than the host and it is not affected by the etch solutions.

The strings parallel a crystallographic direction of the sulphides and it is considered they are exsolution bodies of the chromium sulphide daubreelite. This occurrence is very similar to that in nodules of the Cratheus iron (Curvello, 1958) and in the Packenham meteorite (Edwards and Baker, 1942).

Lawrencite was not identified but its presence was evidenced by the formation of brownish red droplets of iron chloride on unprotected polished surfaces of the iron and nodule. A faint trace of chlorine was detected in the analysis of shavings from the main slice (Table 1, column 2).

CONCLUSIONS

A comparison of the macro-texture and chemical composition of the new meteorite with the same properties of the Gladstone No. 1 shows them to be closely allied. The two meteorites were found only ¾ mile apart and it is believed that others were found in the same area. The Gladstone meteorites are therefore considered to be part of a multiple fall or a shower which fell sometime prior to 1913.

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RECENT INVESTIGATIONS OF THE TENHAM METEORITE SHOWER

By

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ABSTRACT

Some 290 stones with an aggregate weight of approximately 452 lb. have now been recorded from the Tenham shower. The total number of stones collected is believed to substantially exceed this figure.

The H. M. Hammond collection of 36 complete or nearly complete stones is described for the first time. The largest stone in this collection is estimated to weigh 55 lb.

A description is given of thin and polished sections of a 4½ oz. Tenham stone. It is classified as a brecciated, olivine-hypersthene chondrite.

The meteorite track is 14 miles long and up to 8 miles wide. "Ingella" homestead (lat. 25° 33′ S., long. 142° 48′ E.) is centrally situated along the track.

INTRODUCTION

The submission to the Geological Survey of Queensland in 1960 of a meteorite from the Windorah area of south-western Queensland, led to further investigations of the Tenham meteorite shower of 1879. In July 1962 a visit to the scene of the fall was made by the writers and a collection of meteorites in the possession of Mr. H. M. Hammond of "Ingella" station was examined.

This report includes a summary of previous literature, a macroscopic and microscopic description of the meteorite submitted to the geological survey in 1960, and information compiled during the 1962 visit to the Windorah area.

SUMMARY OF PREVIOUS LITERATURE

The fall took place in 1879 but it was not till 1911, when Mr. M. Hammond submitted to the Geological Survey, through Mr. R. A. Wearne, a collection of 15 meteorites, that the Tenham shower was brought to notice. This explains the uncertainty regarding such details as the exact date of the fall and the direction and length of the meteorite track. A further 26 years elapsed before the shower was adequately recorded. L. J. Spencer, formerly Keeper of Minerals at the British Museum brought together the available information and described a collection of 102 meteorites from the Tenham shower (Spencer, 1937).

The shower was observed by Mr. M. Hammond and his brothers who were camped near the junction of Kyabra Creek and Cooper Creek one night in February 1879 (*Queensland Times*, 1911 and *Queensland Government Mining Journal*, 1913). On the day following some of the meteorites were found on the surface and others were embedded two feet or more in the ground. Mr. Hammond claimed that the largest meteorite weighed about 130 lb. but the existence of a stone of this size from the Tenham shower has not been confirmed. Other unconfirmed reports of very large meteorites have originated from aboriginal sources.

The largest Tenham meteorites to be described are two of the Warbreccan stones which weigh 69½ and 64¼ lb. These stones were originally thought to belong to another shower but chemical analyses (see Table 1) and the story behind the collection of the stones indicate that they almost certainly belong to the Tenham meteorite shower (Prior, 1916 and Spencer, 1937).

METEORITE SUBMITTED IN 1960

Macro examination

The meteorite weighs 4½ oz. (128 grams) and measures 2½ x 1⅝ x 1¼ in. (6·35 x 4·13 x 3·18 cm.). Four fairly flat faces are covered by a smooth brown crust about 0·2 mm. thick. The edges and corners are rounded, probably as a result of friction during atmospheric flight. A fifth face is fractured and it appears that a fragment has been broken off. Another incomplete fracture cuts diagonally across the stone. The advanced state of oxidation indicates that the stone had been lying in the open for a considerable time (see plate 5).

No quantitative analysis was made but qualitative tests for nickel gave positive results. Analyses of other meteorites from the Tenham shower are given in Table 1.

TABLE 1

ANALYSES OF TENHAM METEORITES

	A Per cent.	B Per cent.
Fe	7·43	6·03
Ni	1·05	1·06
Co	0·02	0·08
FeS	5·0	6·40
SiO_2	37·8	39·86
Al_2G_3	1·9	1·71
FeO	13·6	12·84
MnO	0·5	0·39
MgO	24·9	24·75
CaO	1·9	2·01
P_2O_5	0·7	0·26
Remainder	5·2	4·67
	100·0	100·06

A. From Mr. Hammond's collection; composition calculated from separate analyses of coarse and fine fractions after crushing and sieving; analyses by Government Chemical Laboratory, Brisbane, 30–9–1913. The remainder was stated as oxygen and undetermined. Ti, Cu and As were absent.

B. From 69 lb. Warbreccan stone. Analysis by G. T. Prior, 1916. The remainder includes TiO_2 0·21%, Fe_2O_3 2·15%, Cu_2O_3 0·41%, NiO 0·12%, Na_2O 0·92%, K_2O 0·06%, H_2O 0·80%.

The specific gravity was determined as 3·41. Sixteen other recorded specific gravity measurements ranged from 3·37 to 3·48 (Spencer, 1937), but two very small stones were found to have specific gravities of 3·34 and 3·28 (Ball, 1939).

Micro examination

Thin sections consisted of approximately 88% transparent silicate minerals and oxides, and 12% opaque metallic minerals and sulphides.

Chrysolite (olivine) and hypersthene are the main silicate minerals, and plagioclase and iddingsite are also present. Due to alteration, the minerals are difficult to distinguish, but the proportion of olivine to hypersthene appears to be more than 2 : 1. The crystals are anhedral and range from 0·3 mm. to 0·01 mm. with an average grain size of 0·15 mm. The extremely fine crystalline material is locally concentrated, thus resembling a cataclasite. Both the chrysolite and hypersthene are heavily fractured and oxidised, and can be distinguished from one another only by the differing birefringence and optic sign. Alteration to dark brown iddingsite has taken place along fractures in the chrysolite. Several irregularly-shaped chondrules are present; these consist of radiating coarse fibres of chrysolite with minor amounts of hypersthene.

In polished section the opaque minerals identified were kamacite, pyrrhotite, troilite and iron oxides; these occur as anhedral grains up to 1 mm. in size distributed between the silicate minerals. The kamacite is white, isotropic and has a high reflectivity; etching with dilute HNO_3 brings out a fine allotriomorphic granular texture.

Of the sulphides pyrrhotite and troilite, the latter is distinguished by its reactivity with dilute HNO_3. Both are a creamy brown colour in reflected light and show a distinct anisotropism exhibiting an allotriomorphic granular texture. The proportion of kamacite to sulphides is approximately 1 : 2.

The dominant oxide mineral is magnetite which shows some alteration to limonite. It occurs as replacements of the kamacite and, to a lesser extent, of the sulphide minerals. Veining of oxides occurs throughout the section.

The meteorite is classified as a brecciated olivine-hypersthene chondrite. Inquiries from Miss Kidd who submitted the meteorite, revealed that it was found on "Ingella", and no doubt remains that it belongs to the Tenham shower.

VISIT TO WINDORAH AREA, 1962

On the 13th, 15th and 16th July, 1962, "Ingella" and "Mayfield" stations were visited and several hours were spent in a search for meteorites. Mr. H. M. Hammond of "Ingella" assisted in the search by providing a four wheel drive vehicle and pointing out localities where meteorites had been picked up. According to Mr. Hammond, meteorites were still being found but the most favourable time for discovery was after heavy rain when the scouring action of flood waters sometimes unearthed stones which had been buried to a shallow depth either on impact or by wind-blown sand. Although no meteorites were found during the visit, much additional information on the meteorite track was obtained, and the examination of the H. M. Hammond collection, though preliminary in nature, has added significantly to the number of Tenham stones officially described.

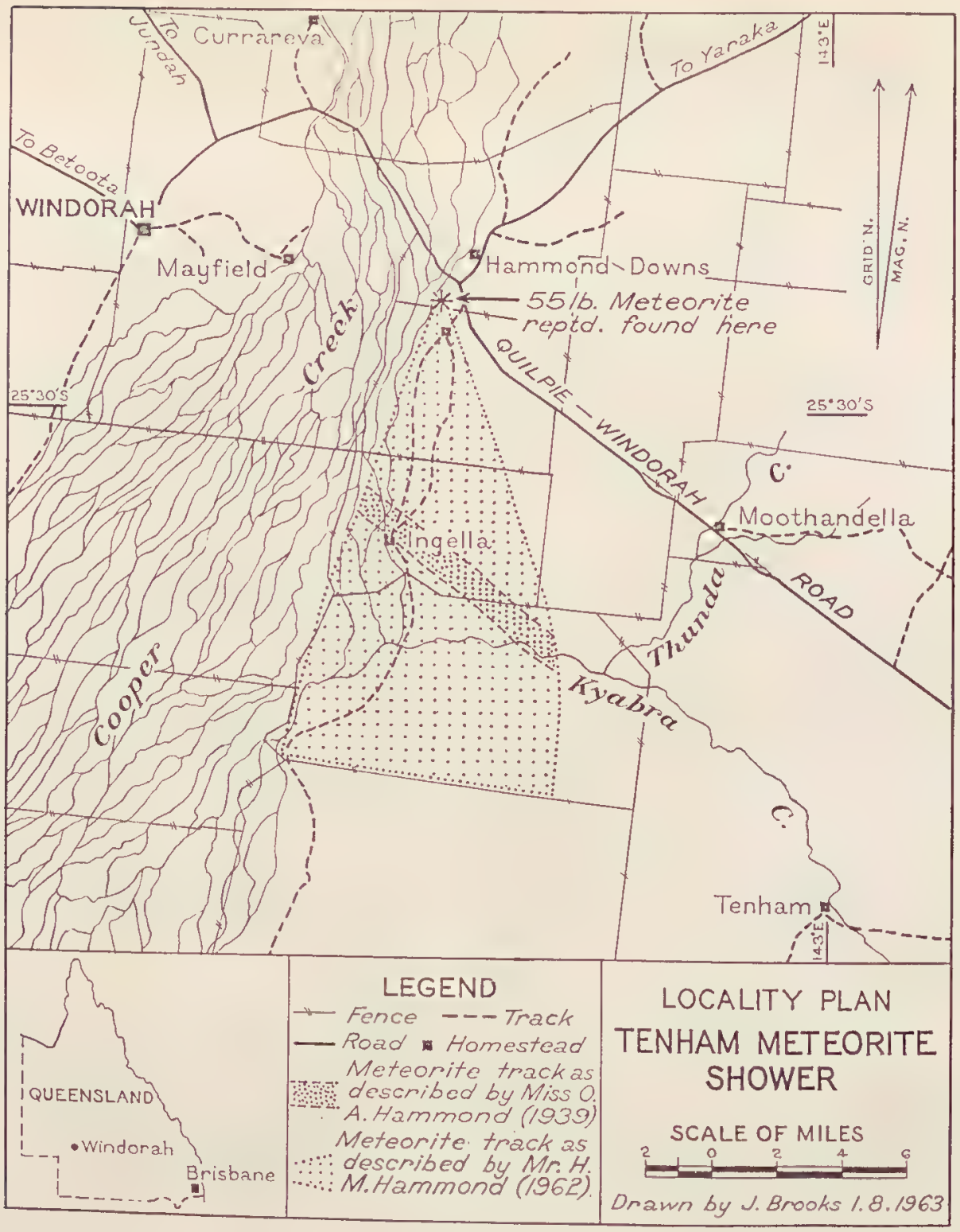
The H. M. Hammond collection consists of 36 complete or nearly complete stones and two fragments. The only means of weighing available at "Ingella" homestead was an old set of kitchen scales so that the figures given in Table 2 are approximate only. The largest stone was beyond the capacity of the kitchen scales and the listed weight of 55 lb. is an estimate based mainly on a comparison with the Warbreccan stones. Among the Tenham stones collected to date it ranks next in size after the Warbreccan stones. Mr. Hammond reported finding the 55 lb. stone about seven miles north of "Ingella" homestead (see locality plan) while working on telephone lines after a period of flood rain (possibly that of 1950).

Apart from the 55 lb. stone the meteorites are unoriented. Most are angular in shape but have rounded edges and fairly smooth faces. Pitting is absent except in a few of the larger stones. Seventeen of the H. M. Hammond collection are roughly equidimensional (i.e. greatest dimension less than twice the least dimension). This contrasts with the collection of 124 stones, purchased by the Queensland Government in 1939, in which 96 stones are roughly equidimensional. The great majority of stones in the British Museum also appear to be equidimensional.

TABLE 2

A. The Inglila Collection of H. M. Hammond

No.	Weight lb.	Weight oz.	Maximum Dimensions (inches)	Minimum Dimensions (inches)	Remarks
1	55	(est.)	15	6	Large rounded front face 15 in. long and 11 in. wide, with a few large pits and rather ragged edges; flat to concave rear face with small pits; three other faces; small fragments have been chipped off from some edges
2	8	12	6½	5½	Seven faces; broken into two pieces and chipped; green stains on surface
3	5	14	5¾	4	Seven faces, some smooth, some pitted
4	2	3	4	2	Four smooth faces, one broken face; a fragment probably broke off before the meteorite landed
5	1	11	4½	2½	Shape irregular
6	1	9	3½	2½	Main faces roughly square shaped; some fragments chipped off
7	1	8	4	2¼	Shape irregular
8	1	8	5½	1½	Fragments broken from two of five faces
9	1	6	4	1½	Five faces; one large fragment broke off along fracture plane
10	1	4	4	1½	Main faces roughly rectangular
11		15½	4	2¼	Roughly pyramidal; broken along fracture plane into two pieces; a few small fragments chipped off
12		10½	3	1¾	Roughly rounded
13		10	3½	1¾	Shape vaguely resembles a Spirifer shell cast
14		10	4	1	Five faces; one large fragment broken off
15		10	2½	1¾	Five faces; roughly rounded
16		9½	3	1½	Roughly oval-shaped; one small fragment broken off
17		8½	2	1½	Roughly rounded
18		7	2½	1½	Five rounded faces, shape irregular
19		6½	2¾	1½	Three main faces; one fragment broken off
20		6½	2½	1½	Rounded faces apart from one broken face
21		6½	2	1¾	Roughly rounded
22		6	4½	1	Unusually long, thin stone
23		5½	2¾	1¼	Roughly egg-shaped
24		4½	2½	1¼	Irregular shape with broken faces
25		4	2¼	1½	Five faces, irregular shape
26		4	2	1½	Five faces
27		2½	2	1½	Six faces
28		2½	2½	1	Three rounded faces, some fragments broken off
29		2	2	1	Four rounded faces, two broken faces
30		1½	1¾	1	Eight faces, irregular shape
31		1	2½	¾	Fragment only; four faces, one broken
32		¾	1¾	¾	Five faces
33		¾	1½	¾	Seven faces
34		½	1½	1	Egg-shaped
35		¼	1¼	½	Six faces
36		¼	1¾	½	Five faces
37		¼	1	½	Very irregular shape
38		¼	1¼	½	Fragment only; one rounded face, one broken. All the stones were dark-brown to brownish-black in colour
B. Miss Kidd's Meteorite					
	1	1	3¾	1½	Six faces, irregular pyramidal form



In addition to the "Ingella" collection Mr. Hammond said that about 20 Tenham stones were in storage at "Tyrone" station near Charleville. The largest of these stones weighs between 5 and 8 lb. and the others are mainly in the ½ to 1 lb. weight range. Another large collection was stated to be in storage at Bryce Ltd. in Brisbane*. The total number of stones in the three H. M. Hammond collections was claimed to be over one hundred.

At "Mayfield" one complete meteorite in the possession of Miss Kidd was examined, and it was confirmed that this and the meteorite submitted to the Geological Survey in 1960, were found on "Ingella".

*Efforts to confirm the existence of the meteorites in storage at Bryce Ltd. were unsuccessful.

METEORITE TRACK

Discussions with Mr. H. M. Hammond provided information which, though not contradictory to earlier reports, does give a rather different picture regarding the extent and direction of the meteorite track. The eye witness account of the fall (*Queensland Times*, 1911) mentions that the shower passed from west to east. Miss O. A. Hammond (personal communication to Mr. L. C. Ball, Chief Government Geologist, 1939) described the track as extending in a south-easterly direction from the west central part of portion 1, parish of Tenham, to beyond Kyabra Creek in portion 5, parish of Tenham (see locality map). Mr. H. M. Hammond has found meteorites within a fan-shaped area extending from the point at which the 55 lb. stone was found, in a southerly direction to

near the southern boundary of "Ingella" station, a distance of 14 miles. "Ingella" homestead (lat. 25° 33′ S., long. 142° 48′ E.) is centrally situated within the fall area. On the west the known fall area borders Cooper Creek, a braided stream with channels extending over a width of 6 miles. As meteorites would be much more difficult to find in the channel country than on the adjacent sparsely-vegetated plain, the limit of the fall in this direction must be regarded as somewhat indefinite.

In general, the size of the stones showed a progressive decrease from the northern part of the track to the south. As the direction of flight is believed to be south-easterly or southerly, the larger stones apparently fell first. This is contrary to what might be expected from theoretical considerations of air resistance and momentum (Spencer, 1937, pp. 449–450), and what has been observed in several other falls (Nininger, 1952, pp. 15, 26, 31 and 195). However, in the well documented Johnstown, Colorado fall of 6th July, 1924, which is similar in many respects to the Tenham fall, the largest stone fell first and the size of the stones became progressively smaller along the path of the fall. (Nininger, 1952, pp. 16–18.)

Although the majority of the smaller Tenham stones are roughly equidimensional, the 55 lb. stone has a shape more nearly approaching a disc and exhibits orientation. Perhaps the greater air resistance offered by this shape offset the effects of momentum. Unfortunately there is no authentic record of where the two large Warbreccan masses were collected. One of these has a shape very similar to that of the 55 lb. stone whereas the other is roughly equidimensional.

A meteorite much larger than any so far collected is reported to be located in the Cooper Creek channel country. Mr. H. M. Hammond stated that the meteorite was in a rather inaccessable area about 12 miles south-west of "Ingella" homestead. This is outside the area where Tenham stones have been found and until the stone is collected, or a fragment from it confirms its identity, not much significance can be attached to the report.

TABLE 3

DISTRIBUTION OF TENHAM METEORITES

Present Location	No. of Stones	Weight or Range of Weight	Total Weight	Remarks
British Museum, London	102 (2 lost)	11½ lb. to 2¾ oz.	113½ lb.	Acquired in 1935 from estate of Mr. B. Dunstan, Chief Govt Geologist, 1908–1930 (Spencer, 1937)
British Museum, London	3	69½, 64¼, 1 lb.	135 lb.	Acquired in 1905 from Mr. R. Pope, an opal buyer—the Warbreccan stones (Prior, 1916)
Queensland Museum, Brisbane ..	118	4 lb. 11 oz. to ½ oz.	104¾ lb.	Purchased by Queensland Government from Miss O. A. Hammond, 1939. (Hodge-Smith, 1939)
Queensland University, Brisbane ..	3			
Geological Survey of Queensland, Brisbane	3 (3 lost)			
Geological Survey of Queensland, Brisbane	3	7, 4¼, 1¼ oz.	12½ oz.	Given to Mr. L. C. Ball, Chief Govt Geologist by Miss O. A. Hammond, 1939. (Geol. Surv. Qld file)
Australian Museum, Sydney ..	1	10½ oz.	10½ oz.	(Hodge-Smith, 1939)
?	14	1 lb. 2 oz. to 2 oz.	6¼ lb.	Loaned to Geological Survey of Queensland by Miss O. A. Hammond, November, 1940, Present whereabouts unknown. (Geol. Surv. Qld file)
Mayfield station, Windorah ..	2	1 lb. 1 oz., 4½ oz.	1 lb. 5½ oz.	In possession of Miss Kidd
Ingella station, Windorah	36	55 lb. to ½ oz.	circa 90	In possession of H. M. Hammond
Tyrone station, Charleville ..	?	up to 8 lb.	?	Stated by Mr. Hammond to comprise about 20 stones up to 8 lb. in weight
In Storage, Bryce Ltd., Brisbane ..	?	?	?	Stated by Mr. Hammond to be a large collection
Totals	290		452¾ lb.	

NUMBER AND WEIGHT OF TENHAM METEORITES

The present distribution of Tenham meteorites is summarised in Table 3. Two hundred and ninety stones weighing in aggregate approximately 452 lb. are in museum collections or have been officially examined. Not included in this total are the remainder of Mr. H. M. Hammond's collection, and a large number of stones which Miss O. A. Hammond stated were given away to relatives (correspondence with Mr. L. C. Ball, 1938). Although the aggregate weight of 452 lb. is much less than some Australian siderites, it is believed that the Tenham shower is the largest Australian aerolite shower, both in weight and in the number of complete or near-complete stones.

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S. G. REID, Government Printer, Brisbane

PLATE 1

Figure 1. Gladstone No. 2, front face.

Figure 2. Gladstone No. 2, rear face, showing direction of major slice.

Figure 1. Gladstone No. 2, side view, showing turned back edges.

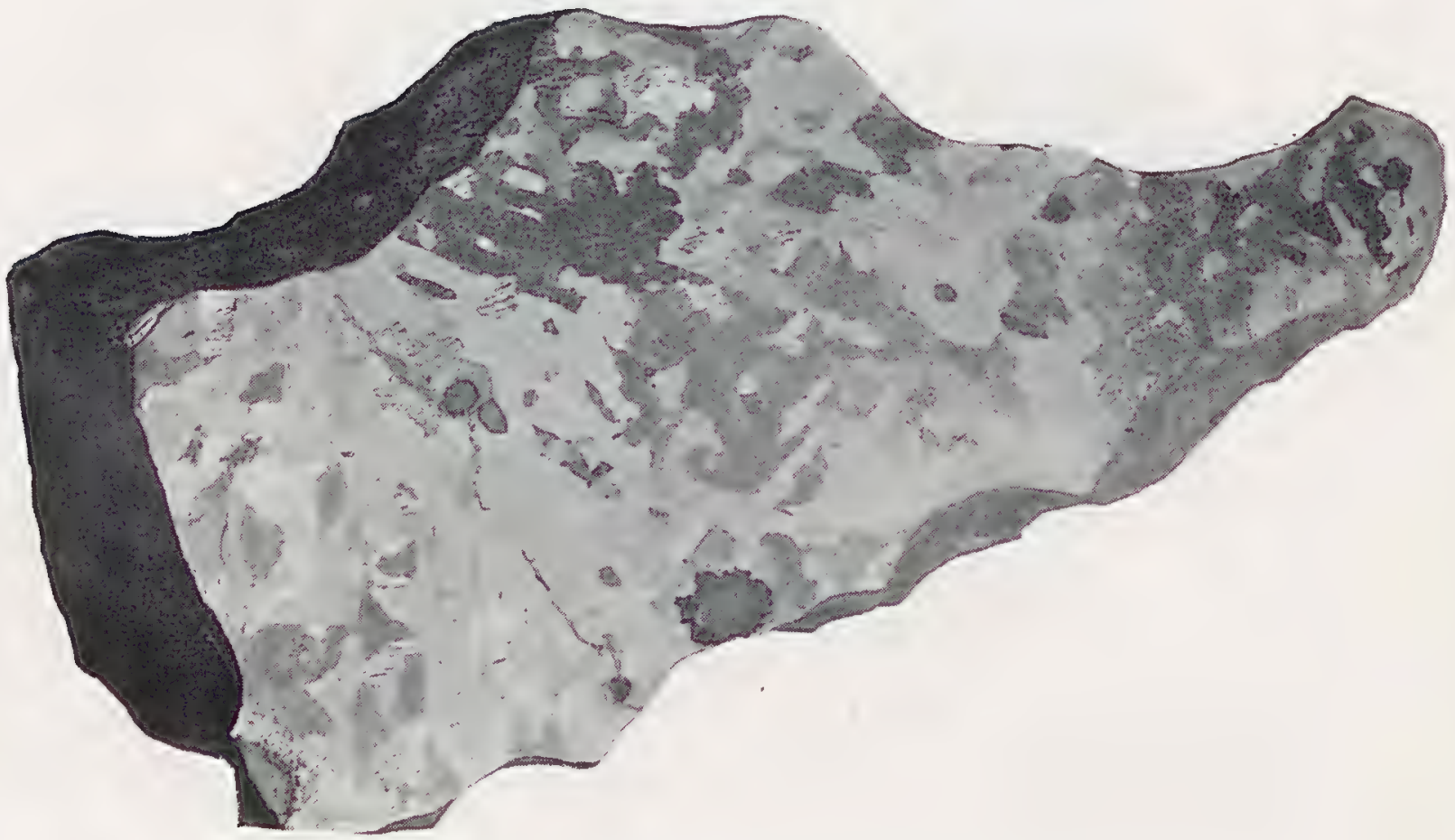
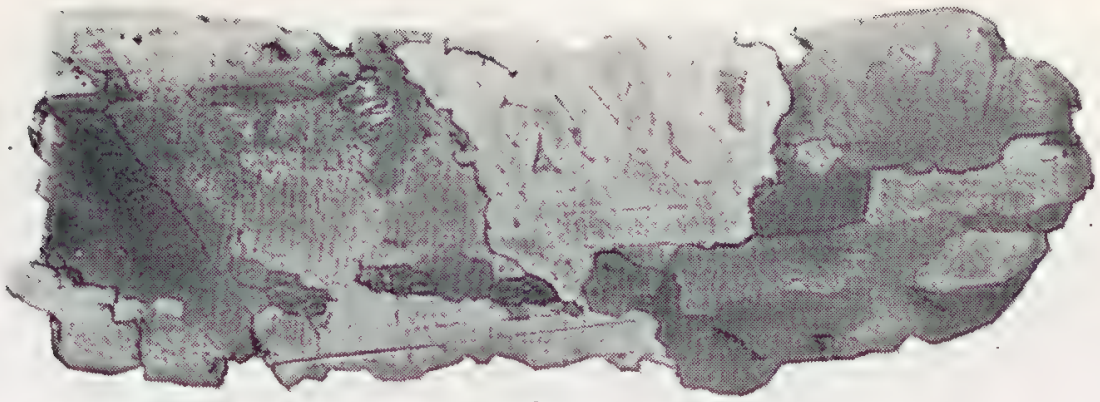


Figure 2. Gladstone No. 2, macro-etched slide, maximum length of section 8·5 in.



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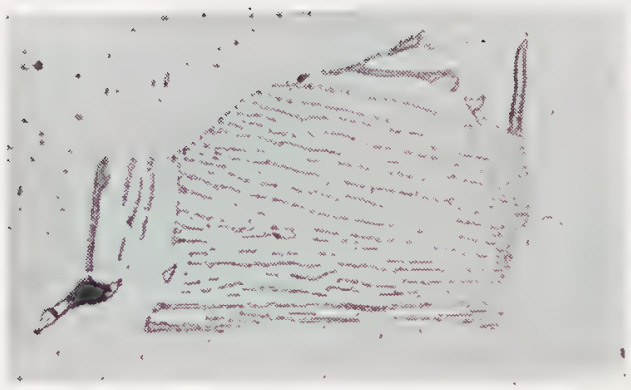

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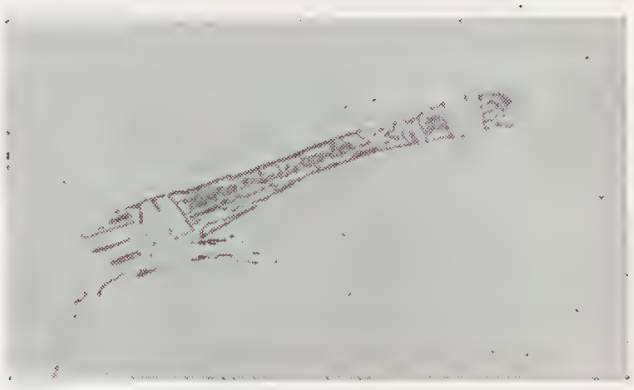

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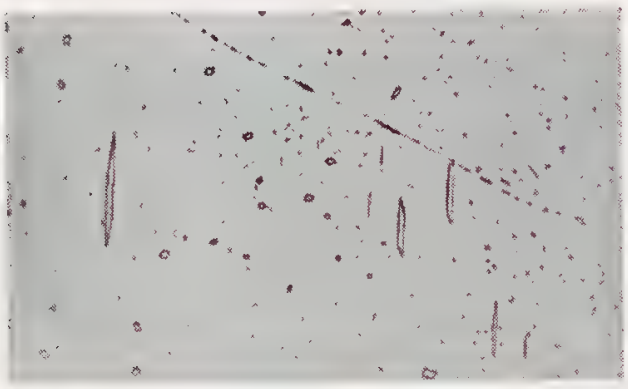

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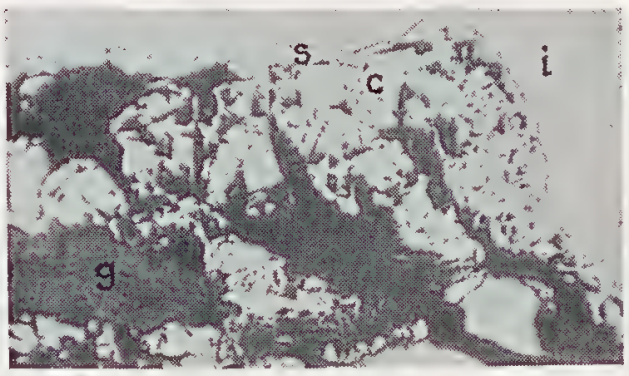

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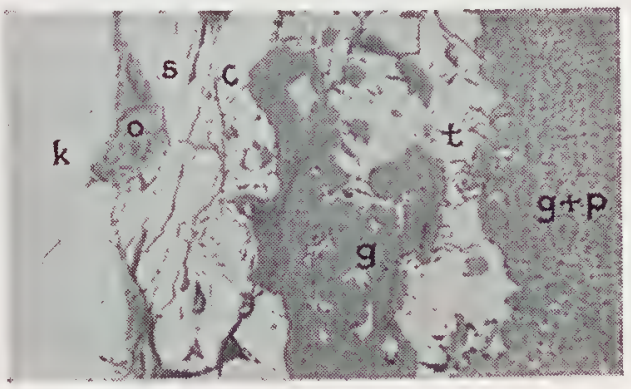

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Figure 1. Macro-etched slice Gladstone No. 1, natural size (*Courtesy Qld Museum*).

Figure 2. Gladstone No. 2, plessite field, some small grains of schreibersite are also in evidence, × 34.

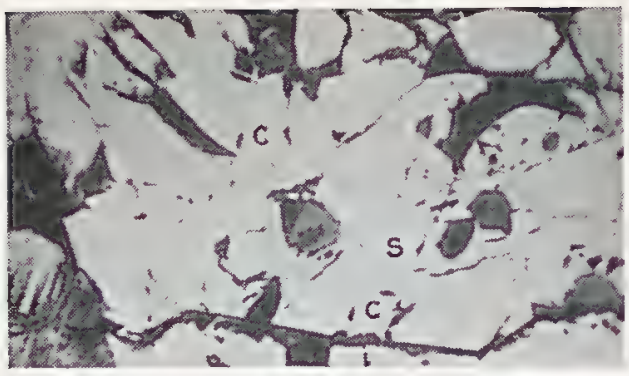
Figure 3. Plessite and dense plessite, × 34.

Figure 4. Rhabdites in long- and cross-section, × 66.

Figure 5. Portion of compound vein showing graphite (g), cohenite (c), schreibersite rim (s) and iron (i), × 34.

Figure 6. Portion of same vein, copper etch, schreibersite unaffected, × 34.

Figure 7. Rim of large nodule showing pyrrhotite-graphite core (p + g), troilite (t), graphite (g), cohenite (c), schreibersite (s), oxide (o) and swathing kamacite (k), × 34, unetched.



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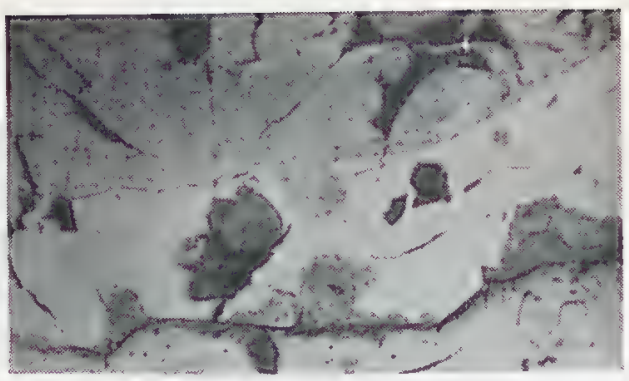

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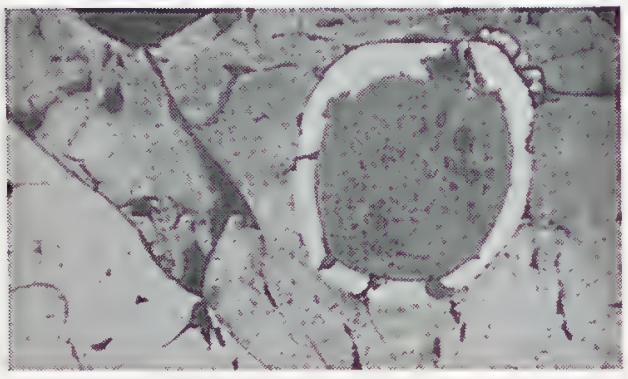

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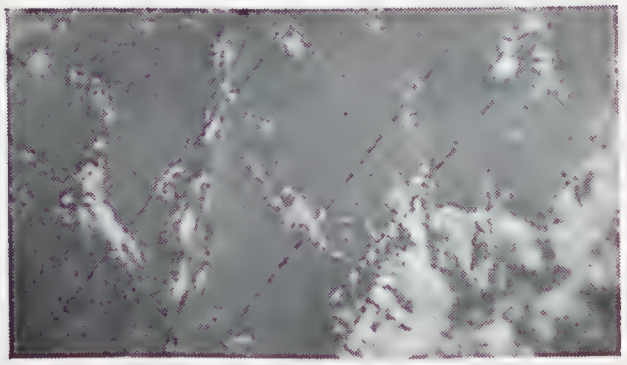

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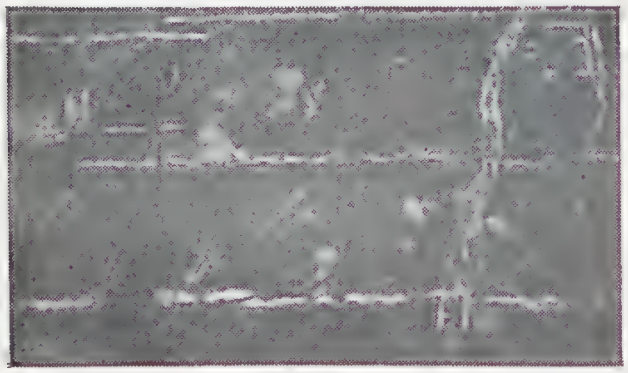

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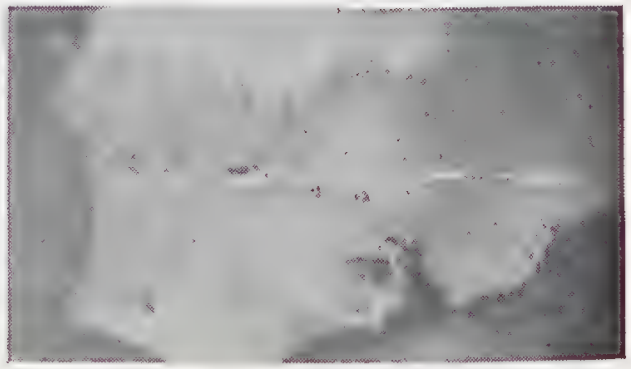

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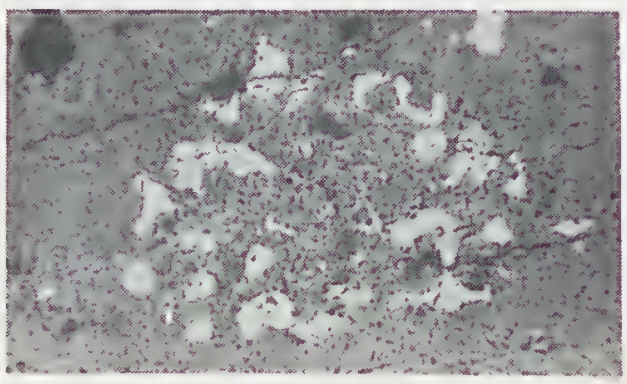

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Figure 1. Portion of nodule rim showing cohenite (c), schreibersite (s) and iron (i), × 66.

Figure 2. The same after copper etching.

Figure 3. Another portion of nodule rim showing oxide rimmed with schreibersite, copper etch, × 66.

Figure 4. Exsolution bodies of ?daubreelite in troilite, cross nicols, × 260.

Figure 5. Exsolution of ?daubreelite in pyrrhotite, 4% Picral, × 130.

Figure 6. Exsolution of ?daubreelite in troilite, 4% Picral, × 640.

Figure 7. Tenham stone, enstatite chrondite, reflected light, × 260.

Figure 1. Tenham stone submitted by Miss Kidd to the Geological Survey of Queensland for examination in 1960.

Figure 2. Polished face of Tenham stone.

Figure 1. Early photo of a collection of Tenham meteorites which was given to Mr. R. A. Wearne by Mr. M. Hammond.

Figure 2. H. M. Hammond collection of Tenham meteorites.

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QUEENSLAND
DEPARTMENT OF MINES

GEOLOGICAL SURVEY OF QUEENSLAND

(A. K. Denmead, M.Sc., Chief Government Geologist)

PUBLICATION No. 321

TRIASSIC SPORES AND POLLEN GRAINS FROM THE BUNDAMBA GROUP

By N. J. de JERSEY, Ph.D., M.Sc., Supervising Geologist

BRISBANE
By Authority: S. G. REID, Government Printer
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Preface

This paper by Dr. N. J. de Jersey is based on eighteen samples from the Bundamba Group of the type area. It is the fourth in a series on the major sedimentary formations of Queensland, previous Publications (Nos. 294, 307 and 313) having dealt with the Walloon Coal Measures, Ipswich Coal Measures and Marburg Sandstone. A detailed investigation of the Bundamba microflora has led to the discovery of species which, in Europe, are of restricted range in the Alpine Triassic succession. This discovery has thus enabled the Bundamba sediments to be related closely, in age, to parts of the standard Austrian Triassic sequence. Such a degree of precision has not previously been achieved in correlation of non-marine Triassic sediments in Queensland.

The investigation has demonstrated that formations in the Surat sub-basin, which contain Jurassic microfloras, are significantly younger than the Bundamba Group of the type area. Application of the term "Bundamba" to these formations, which are currently being prospected for oil and gas reservoirs, should accordingly be discontinued. The results of the present work should also find application in correlation studies in Triassic sediments of the Surat sub-basin, which are now in progress.

A. K. DENMEAD,
Chief Government Geologist.

TRIASSIC SPORES AND POLLEN GRAINS FROM THE BUNDAMBA GROUP

By N. J. de Jersey, Ph.D., M.Sc., Supervising Geologist

ABSTRACT

Microfloral assemblages from eighteen samples from the Bundamba Group, in south-eastern Queensland, have been examined. The samples came from a section covering about 1,200 feet in stratigraphic thickness, in the type area of the Group. From the taxonomic aspect, thirty-seven species are recorded; of these, six are proposed as new species, and four as new combinations. Emendations of the generic diagnoses of Stereisporites, Vitreisporites *and* Discisporites *are proposed. From the stratigraphic aspect, the whole of the sequence examined is regarded as Triassic; the evidence favours a Karnian (early Upper Triassic) age, with a possible upward extension into the succeeding Norian. Previous application of the term "Bundamba" to Jurassic sediments in the Artesian Basin is discussed—in view of the distinct difference in age now demonstrated continuance of this usage is not recommended. It is concluded that precise time equivalents of the Bundamba Group have not yet been found elsewhere in Queensland.*

I. INTRODUCTION

The Bundamba Group comprises a sequence of sediments in the Ipswich district of south-eastern Queensland. At its base it overlies disconformably the Ipswich Coal Measures, of Triassic age; the relationship to the Jurassic Marburg Sandstone is uncertain and the possible existence of an unconformity between the Group and this formation has been indicated (Denmead 1955, p. 6). The stratigraphic nomenclature of the Bundamba Group has recently been clarified by Staines (1964), who has discussed the lithologic sequence and defined three formations in terms of the Australian Code of Stratigraphic nomenclature. These are, in ascending stratigraphic order, the Aberdare Conglomerate, the Raceview Formation and the Ripley Road Sandstone. The lithology of these units (based on Staines 1964, pp. 33-35) can be summarised as follows:—

(1) The Aberdare Conglomerate (average thickness 40 ft.) consists of cobble and pebble conglomerates, sandstone, siltstone and thin carbonaceous shale. It overlies disconformably the Blackstone Formation (of the Ipswich Coal Measures) and is overlain conformably by the Raceview Formation

(2) The Raceview Formation (average thickness 390 ft.) consists of interbedded sandstone, siltstone, shale and a few thin coal seams. It is conformable with both the underlying Aberdare Conglomerate and the overlying Ripley Road Sandstone.

(3) The Ripley Road Sandstone consists almost entirely of fine to coarse massive sandstone, with a few thin siltstone bands. Its thickness is 737 ft. in the type section, but total thickness could be considerably greater (up to 1,200 ft.). It conformably overlies the Raceview Formation but its upward relationships are not clear.

The first direct palaeontological evidence on the age of the Bundamba Group was provided by Jones and de Jersey (1947), who recorded macrofloras from shales in the Raceview Formation. These floras were typically Triassic in character, being dominated by *Dicroidium,* and lacking any distinctive Jurassic species. On this macrofloral evidence, an Upper Triassic age was suggested for the Group (Jones and de Jersey 1947, p. 83).

The investigation of the microflora, recorded here, is based on samples from each of the three formations listed above. Its purpose has been to record and describe the species present and to apply microfloral evidence in determining the age and stratigraphic relationships of the Group. From the latter aspect it was hoped to achieve a more precise dating of the Bundamba sequence; this would enable its relationship with other sequences, previously correlated with the Group on the basis of lithological similarity, to be evaluated. Of particular interest would be evidence on the relationship with sediments underlying the Walloon equivalents in the Surat sub-basin, which have been placed in the "Bundamba Group" or "Bundamba Formation" by various authors. These sediments contain Jurassic microfloras (de Jersey and Paten 1963*a*). Hence proof that they were time equivalents of the "Bundamba Group" of the type area would require the discovery of similar Jurassic assemblages in the latter.

II. SAMPLES EXAMINED

The lithology of the Bundamba Group is dominated by sandstone, often coarse and massive and unlikely to yield abundant, well preserved spores and pollens. The investigation has, accordingly, been

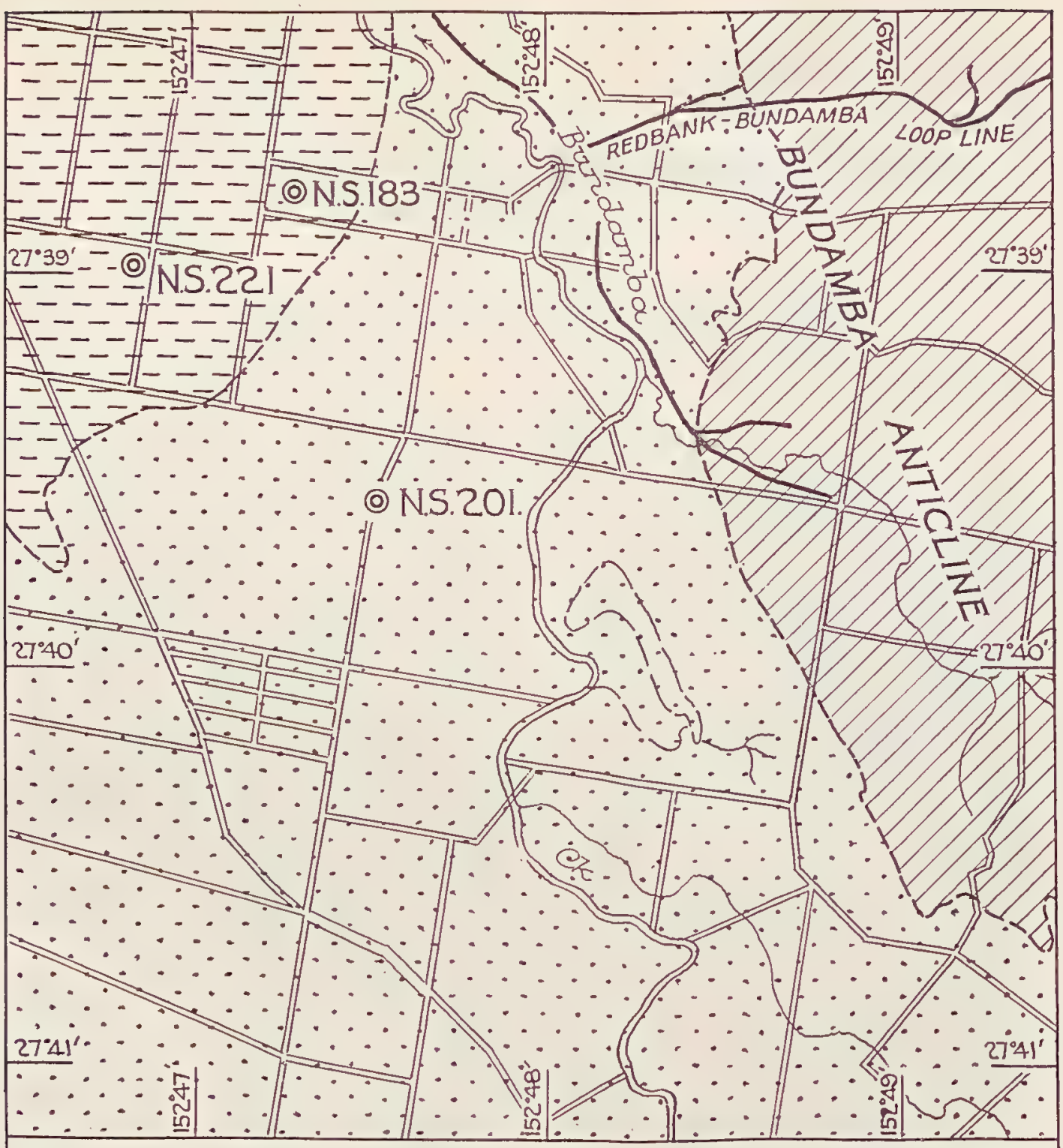

FIG. 1 : SKETCH MAP OF SAMPLE LOCALITIES

SCALE OF CHAINS

40 20 0 40 80

— LEGEND —

TERTIARY (Undifferentiated volcanics and sediments)

TRIASSIC - BUNDAMBA GROUP - (Undifferentiated)

TRIASSIC - IPSWICH COAL MEASURES - (Undifferentiated)

(Geology after Freytag, 1963, Fig. 2)

Drawn at The Dept. of Mines, Brisbane Feb 1964

L.P.H.

based on the interbedded shales, siltstones and coals. The proportion of these fine sediments is greatest in the Raceview Formation, from which, consequently, most of the samples examined have been obtained. The highest formation, the Ripley Road Sandstone, consists almost entirely of massive sandstone, but fortunately a few thin bands of siltstone (of the order of one inch in thickness) were present in the section. Samples from three such bands have yielded abundant spores and pollens, thus providing data on this unit, which is dominantly of lithology unsuitable for detailed microfloral studies.

Sampling of these formations was greatly assisted by Departmental drilling in their type areas, particularly as most of the drillholes have been continuously cored through the Bundamba sequence. Mines Department drillhole N.S. 201 was selected for detailed sampling, as a continuous core had been kept from a depth of 300 ft. downwards, thus covering the complete sequence of the Aberdare Conglomerate and Raceview Formation, together with the bottom 230 ft. of the Ripley Road Sandstone. In all, sixteen samples from this drillhole were examined. Two additional samples, from drillholes N.S. 221 and N.S. 183, were also studied. The former was selected to provide an additional sample from the Ripley Road Sandstone; it came from a level about 670 ft. above the base of that unit and was, stratigraphically, the highest sample in the sequence examined. The sample from N.S. 183 consisted of coal from the Little West Moreton seam. This sample was studied because the seam (the only one mined in the Group) is missing from the sequence in N.S. 201, having evidently lensed out between there and N.S. 183. The positions of these three drillholes are shown in the locality map (Figure 1). The levels of the formation boundaries and contacts with the underlying Ipswich Coal Measures and overlying Tertiary sediments (H.R.E. Staines, Verbal communication) are summarised below in Table 1.

TABLE 1

FORMATION BOUNDARIES IN N.S. 183, N.S. 201 AND N.S. 221

—	Depths of boundaries in N.S. 183	Depths of boundaries in N.S. 221	Depths of boundaries in N.S. 201
	Ft.	Ft.	Ft.
Tertiary sediments ..	240	240	(Tertiary absent)
Ripley Road Sandstone ..	576	1,117	532
Raceview Formation ..	1,041	1,523	969
Aberdare Conglomerate ..	1,085	1,629	1,049
Blackstone Formation (Ipswich Coal Measures)			

In Table 2, below, are listed the samples examined, arranged in descending stratigraphic order. This order is based on the sequence in N.S. 201; the other two samples (from N.S. 183 and N.S. 221) have been inserted in appropriate positions in this sequence. The position of the samples from N.S. 183 (from the Little West Moreton seam) is approximate only, as this seam is missing from the sequence in N.S. 201. It is consequently based on the normal interval between the seam and the base of the Raceview Formation. No such problem exists in the case of the sample from N.S. 221; being, stratigraphically, the highest sample examined, it is placed at the top of the sequence. Also listed in Table 2 are the formations from which the samples were derived, the lithology of each sample and the number of spore and pollen specimens examined in each case.

TABLE 2

LIST OF SAMPLES EXAMINED

Formation	Departmental drillhole No.	Depth	Lithology	Number of specimens examined
		Ft. In.		
Ripley Road Sandstone	N.S. 221	455 0	Siltstone	500
Ripley Road Sandstone	N.S. 201	313 7	Siltstone	500
Ripley Road Sandstone	N.S. 201	432 9	Siltstone	200
Raceview Formation	N.S. 201	540 4	Shale	500
Raceview Formation	N.S. 201	578 5	Coal	500
Raceview Formation	N.S. 201	585 0	Carb. shale	200
Raceview Formation	N.S. 201	632 6	Carb. shale	500
Raceview Formation	N.S. 201	685 3	Carb. shale	500
Raceview Formation	N.S. 201	718 7	Carb. siltstone	500
Raceview Formation	N.S. 201	789 8	Carb. shale	500
Raceview Formation	N.S. 183	851 7½ to 854 0	Coal (L. W. Moreton seam)	200
Raceview Formation	N.S. 201	821 8	Carb. shale	500
Raceview Formation	N.S. 201	842 3	Carb. shale	500
Raceview Formation	N.S. 201	892 10	Coal	200
Raceview Formation	N.S. 201	923 0	Carb. shale	200
Aberdare Conglomerate	N.S. 201	958 7	Carb. shale	500
Aberdare Conglomerate	N.S. 201	982 2	Carb. shale	500
Aberdare Conglomerate	N.S. 201	1,027 11	Carb. shale	500

III. EXPERIMENTAL METHOD

The technique used for maceration of shales and siltstones was substantially similar to that previously described (de Jersey 1963, pp. 1 and 2). The samples were first treated with dilute hydrochloric acid to remove calcium carbonate, if necessary. Silicates were then decomposed by heating in hydrofluoric acid at its constant boiling point concentration, aluminium fluoride formed in the process being removed by treatment with dilute hydrochloric acid. The carbonaceous matter liberated was treated with Schulz solution (potassium chlorate and concentrated nitric acid) for periods from half an hour to two hours, and then finally washed with dilute sodium hydroxide solution. The residue was washed to neutrality at each stage of the process, using a centrifuge for this purpose. Coals were macerated by a modified version of this technique, treatment with hydrofluoric acid being omitted.

The final maceration residue was mounted on microslides, using Canada balsam-xylol solution as the mounting medium. The micro-slides were traversed systematically with the aid of a mechanical stage, 200 or 500 specimens being examined according to the relative abundance of spores and pollens (see Table 2 above). Specimens selected for photographing were located with a Carl Zeiss (Oberkochen) microscope by means of their stage co-ordinates expressed to the nearest 0·1 mm. In addition the co-ordinates of an easily located reference point, selected as the lower right-hand corner of the cover glass of each slide, have been determined in each case. This reference point is quoted in the text, along with the co-ordinates of each holotype or figured specimen, so that with this informatiton the specimens can be readily located by means of any microscope equipped with a mechanical stage. The micro-slides are stored in the palynological collection of the Geological Survey of Queensland, being numbered in the Ipswich coalfield section of the collection.

Photographs were taken using a Leitz "Makam" camera attachment and an oil immersion (X100) objective. Negatives were made directly on "Kodalith" Panchromatic plates from which contact prints were produced on Velox glossy paper. The approximate magnification is X1000 in all cases.

IV. CLASSIFICATION OF SPORES AND POLLEN GRAINS

The spores and pollens recorded have been described as genera and species on the basis of accepted taxonomic procedure. Instead of using an artificial system of supra-generic classification, based on morphology, the genera have been arranged, as far as possible, to indicate affinities with natural groups. It is considered that sufficient is either known or can be inferred regarding the affinities of Mesozoic microfloras for this step to be taken. The writer is in agreement with Balme, who stated (1963, p. 15): "Taxonomic criteria are based on the publication of Potonié and Kremp (1954), and subsequent papers by Potonié. Certain of the suprageneric form taxa proposed by Potonié and Kremp and later authors have also been adopted. However, no attempt has been made to apply the all-embracing scheme of higher form categories favoured by many recent workers. This system has certain advantages in bringing apparent order to the bewildering variety of trilete spores in Upper Devonian and Carboniferous microfloras. Nevertheless, it seems unwise, at this stage of our knowledge of the morphology and affinities of fossil spores, to obscure possible natural relationships by over-rigid codification".

V. SYSTEMATIC DESCRIPTIONS

? Fungal Spores

Genus INAPERTISPORITES van der Hammen ex Rouse

Inapertisporites minutus (de Jersey) de Jersey

Remarks.—The specimens recorded are similar to those previously described from the Walloon Coal Measures, Ipswich Coal Measures and Marburg Sandstone (de Jersey 1959, p. 359; 1962, p. 2; 1963, p. 3).

Inapertisporites crassus (de Jersey) de Jersey

Remarks.—The specimens recorded are similar to those previously described from the Walloon Coal Measures, Ipswich Coal Measures and Marburg Sandstone (de Jersey 1959, p. 359; 1962, p. 2; 1963, p. 3).

? Division BRYOPHYTA

Genus STEREISPORITES Pflug, Emend.

Type Species.—*Stereisporites stereoides* (Potonié and Venitz) Pflug.

Emended diagnosis.—Small spores (diameter less than 50 microns). Amb rounded triangular to subcircular. Trilete, laesurae straight, without conspicuous development of lips, tori or other features. Exine smooth or scabrate, relatively thick (1·5 to 2 microns or more), rigid, frequently with slight thickenings at angles of equator.

Remarks.—Manum (1962, p. 26) showed that *Stereisporites* has priority over *Sphagnumsporites* as a generic name for spores of this type, as follows:—"Potonié (1956b, p. 17) provided a description for the genus *Sphagnumsporites* Raatz (1937, p. 9) and regarded *Stereisporites* Pf. as a later synonym. However, since Raatz did not describe his *Sphagnumsporites*, the date of its valid publication is that of Potonié's description (cp. p. 16). Thus *Stereisporites* has priority and *Sphagnumsporites* must be treated as a later synonym."

The generic diagnosis is emended here so as to include spores with distal polar thickening, as in *S. antiquasporites* (Wilson and Webster) Dettmann, recorded below. Another species with distal thickening is *S. perforatus* Leschik (Leschik 1955, p. 10, pl. 1, figs. 3, 4). This species was included in *Stereisporites* by Leschik and by Playford and Dettmann (1964) although the latter authors stated "*S. perforatus* has a distally thickened exine and is not strictly conformable with *Stereisporites* as defined by Pflug."

Proposal of a new genus to incorporate such distally thickened forms has been considered. However as there is considerable variation in the distinctness of the distal thickening (evident in specimens from the Mesozoic of Queensland), it seems desirable to take the alternative course of widening the scope of *Stereisporites* so as to include them, thus regarding the distal thickening as a character of importance at the specific level. Two other genera with distal thickening are *Annulispora* de Jersey 1959 and *Distalanulisporites* Klaus 1960, but in each of these the distal thickening is in the form of a ring surrounding an area of unthickened exine, so that forms like *S. antiquasporites* could not be included in either genus.

The other principal emendation is in incorporating an arbitrary size criterion (less than 50 microns) into the generic diagnosis. This feature, while not made a definite generic character by previous authors, is however in accordance with their views on the circumscription of the genus.

Stereisporites tenuis (de Jersey), new combination

1959. *Sphagnumsporites tenuis* de Jersey, Qld Govt Min. J. **60**, 348, pl. 1, fig. 3.

1962. *Sphagnumsporites tenuis* de Jersey, Geol. Surv. Qld Publ., **307**, 3, pl. 1, figs. 7, 8.

1963. *Sphagnumsporites tenuis* de Jersey, Geol. Surv. Qld Publ., **313**, 3.

Remarks.—In accordance with Manum's treatment of *Sphagnumsporites* as a later synonym of *Stereisporites* (Manum 1962, p. 26) this species is here transferred to *Stereisporites* as a new combination. The specimens from the Bundamba samples are similar in all features to those previously described and figured from the Walloon and Ipswich Coal Measures.

Stereisporites antiquasporites (Wilson and Webster) Dettmann

Plate 1, Figures 1, 2 and 3

Description (based on Bundamba specimens).—Amb sub-triangular to circular. Diameter (based on 63 measured specimens) 25 to 40 microns. Laesurae distinct, length about two-thirds spore radius. Darker sub-circular thickened area at distal pole, diameter equal to, or slightly less than, spore radius. Thickness of exine (measured at equator) 1·5 to 3 microns. Exine smooth, light yellow to brownish yellow.

Figured specimen (Plate 1, Figure 1).—Slide No. 431; Stage co-ordinates 43·0, 90·0; diameter 35 microns. Co-ordinates of lower right-hand corner of cover glass, 47·5, 84·5.

Figured specimen (Plate 1, Figure 2).—Slide No. 436; Stage co-ordinates 32·0, 95·8; diameter 35 microns. Co-ordinates of lower right-hand corner of cover glass 47·6, 86·7.

Figured specimen (Plate 1, Figure 3).—Slide No. 432; Stage co-ordinates 34·0, 98·5; diameter 36 microns. Co-ordinates of lower right-hand corner of cover glass 46·8, 85·4.

Remarks.—The Bundamba specimens agree, in all essential features, with the holotype of Wilson and Webster (1946, p. 273, fig. 2). They are also similar to specimens recorded from the Cretaceous of South-eastern Australia by Dettmann (1963, p. 25; pl. 1, figs. 20, 21), slight differences being the presence of slight thickenings in the radial regions at the equator and the slightly smaller distal thickening in spores described by the latter author. Variation can be expected in both these features, however, and in view of the simple construction of these spores, it is considered preferable to adopt a broad interpretation of the species. On this basis, the Rhaetic *Sphagnumsporites apolaris* Reinhardt (1962), which comprises spores very similar to the Bundamba specimens, is also regarded as synonymous with *S. antiquasporites*.

In the Bundamba samples *S. antiquasporites* is abundant (30·5 per cent.) in coal from the Little West Moreton seam (N.S. 183, 851 ft. 7½ in. to 854 ft.) but rare elsewhere. The species has also been observed in samples from the Jurassic Precipice Sandstone of the Surat sub-basin.

Division LYCOPODOPHTYA
Order LYCOPODIALES
Family LYCOPODIACEAE
Genus LYCOPODIUMSPORITES Thiergart

Lycopodiumsporites antiquus, new species

Plate 1, Figure 5

Diagnosis.—Amb triangular to sub-circular. Equatorial diameter (based on 40 measured specimens) 33 to 56 microns. Trilete; where evident, narrow inconspicuous laesurae extend almost to equatorial margin. Distal surface reticulate; lumina suboval to sub-circular, 2 to 3 microns in diameter; muri 1·5 to 2 microns in width and about 1 micron in height. Ornament extending from equator up to 5 microns on proximal surface, remainder of proximal surface smooth. Exine of medium thickness, light yellow to brownish yellow.

Holotype (Plate 1, Figure 5).—Slide No. 374; Stage co-ordinates 44·4, 102·7; diameter 46 microns. Co-ordinates of lower right-hand corner of cover glass 44·7, 93·3.

Locality of holotype.—Mines Department drill-hole N.S. 201 (Ipswich coalfield), 718 ft. 7 in.

Remarks.—*L. antiquus* differs from the genotype *L. agathoecus* (R. Potonié) Thiergart in being distinctly smaller, and in having appreciably smaller lumina. In the latter feature and in having less prominent laesurae, it also differs from *L. circolumenus* Cookson and Dettmann. It has less in common with *L. clavatoides* Couper and *L. gristhorpensis* Couper. *L. austroclavatidites* (Cookson) Cookson and Dettmann and *L. rosewoodensis* (de Jersey) de Jersey differ in having larger lumina, which are more polygonal in shape in both those species.

Division PTEROPHYTA
Class FILICOPSIDA
Order FILICALES
Family OSMUNDACEAE
Genus OSMUNDACIDITES Couper

Osmundacidites wellmanii Couper

Remarks.—Pocock (1962, p. 35) regards *Baculatisporites comaumensis* (Cookson) Potonié as a synonym of *O. wellmanii*. Playford and Dettmann (1964), on the other hand, consider the species to be distinct. The Bundamba material does not throw any light on this problem, as it is lacking in specimens with closely packed sub-bacula (the type of ornament specified by Cookson as a diagnostic feature of *B. comaumensis*). Hence it has not been possible to determine whether the gradation in ornament between the two specific types, reported by Pocock, also occurs in Queensland. It is hoped that study of additional material from the Jurassic will provide further evidence.

Osmundacidites sp.

Plate 1, Figure 6

Description.—Amb circular, frequently distorted by folding, periphery finely notched. Trilete, laesurae straight and extending about ¾ of the distance to the equator. Diameter (based on 30 measured specimens) 56 to 89 microns (mean 75 microns). Exine 1 to 2 microns thick, sculptural elements small and varied, including cones and grana (average diameter 1·5 microns) and bacula (average dimensions 2 x 1 microns).

Figured specimen (Plate 1, Figure 6).—Slide No. 340; Stage co-ordinates 38·0, 92·7; max. diameter 74 microns. Co-ordinates of lower right-hand corner of cover glass 46·7, 84·3.

Remarks.—The spores recorded here are appreciably larger than either *O. wellmanii* or *B. comaumensis*. In size they are comparable with *O. senectus* Balme (Balme 1963, p. 17), but their ornamentation is less regular than in Balme's species. In addition baculate processes appear to be more frequent in the Queensland specimens.

? Family MATONIACEAE
Genus DICTYOPHYLLIDITES Couper

Dictyophyllidites mortoni (de Jersey) Playford and Dettmann

Description (Playford and Dettmann, 1964).—Microspores radial, trilete, biconvex, the distal surface strongly arched. Amb subtriangular with concave to convex sides. Laesurae straight, length greater than three-quarters radius of spore; enclosed by membranous, elevated (1-2 microns high) lips. Exine 1-2 microns thick, smooth; with exinal thickenings (2-5 microns wide) about the margins of the laesurae. Proximal exine usually with a Kyrtome the limits of which parallel the laesurae. In compressed specimens the Kyrtome is reduced to three arcuate folds.

Dimensions.—Equatorial diameter 28 (36) 45 microns; polar diameter (4 specimens) 35 (36) 38 microns.

Remarks.—On the basis of the presence of elevated laesurate lips and proximal exinal thickenings, Playford and Dettmann (1964) have transferred this species from *Concavisporites* to *Dictyophyllidites*. They have also noted the striking resemblance to microspores obtained from *Phlebopteris polypodioides* Brongniart and so affinity with the Matoniaceae may be suggested.

? Family DIPTERIDACEAE
Genus CONVERRUCOSISPORITES Potonié and Kremp

Converrucosisporites cameroni (de Jersey) Playford and Dettmann

Description (Playford and Dettmann, 1964).—Microspores radial, trilete; biconvex with strongly arched distal side. Amb sub-triangular with broadly rounded apices and slightly convex, straight, or slightly concave sides. Laesurae perceptible to distinct, straight or slightly curved, simple, length at least two-thirds amb radius. Irregular, relatively fine, exinal sculpture consisting mostly of verrucae, together with some bacula, spinae, coni, and grana. Projections 0·5-2·5 microns high; with circular to oval bases (diameter 0·5-3 microns) that rarely coalesce and are up to 7 microns apart (average 2 microns). Sculpture more prominent distally and equatorially than on proximal face where projections may be either almost absent or very much reduced in size and density. Exine otherwise laevigate or scabrate, approximately 1 micron thick. One or two compression folds in some specimens.

Dimensions.—Equatorial diameter 34 (43) 52 microns.

Remarks.—On the basis of its sub-triangular amb, Playford and Dettmann (1964) have transferred this species from *Verrucosisporites* to *Converrucosisporites*. They have noted the striking similarity to a spore derived from *Clathropteris meniscoides* Brongniart, thus indicating affinity with the Dipteridaceae.

Spores—Incertae Sedis

Genus PUNCTATISPORITES (Ibrahim) Potonié and Kremp

Punctatisporites sp.

Remarks.—The specimens recorded here are thin, smooth, trilete spores of circular outline, mostly 25 to 40 microns in diameter, without development of lips. Because of the lack of ornamentation and other distinctive features specific differentiation of this generalised spore type has not been attempted.

Genus LEIOTRILETES (Naumova) Potonié and Kremp

Leiotriletes directus Balme and Hennelly

Remarks.—There is nothing to add to previous descriptions and illustrations of this generalised type of spore.

Genus GRANULATISPORITES (Ibrahim) Potonié and Kremp

Granulatisporites minor de Jersey

Remarks.—Specimens of this species are similar to those previously from the Walloon Coal Measures, Ipswich Coal Measures and Marburg Sandstone (de Jersey 1959, p. 356; 1962, p. 5; 1963, p. 5).

Genus FOVEOSPORITES Balme

Foveosporites moretonensis, new species

Plate 1, Figures 7 and 8

Diagnosis.—Amb rounded triangular to circular. Diameter (based on 20 measured specimens) 28 to 38 microns. Trilete mark with well defined laesurae, half to two-thirds spore radius, thickened lips up to 2 microns in width. Distal face ornamented with irregular pits and short channels (average diameter 1·5 to 3 microns) separated by irregular ridges 1 to 2 microns in width, the ornament being suggestive of an indistinct reticulum. Ornament reduced on proximal face. Exine light yellow to brownish yellow, with slight equatorial thickening (up to 2 microns).

Holotype (Plate 1, Figure 7).—Slide No. 436; Stage co-ordinates 32·0, 90·3; diameter 35 microns. Co-ordinates of lower right-hand corner of cover glass 47·6, 86·8.

Locality of holotype.—Mines Department drillhole N.S. 183 (Ipswich Coalfield); coal from 851 ft. 7½ in. to 854 ft. (Little West Moreton seam).

Figured specimen (Plate 1, Figure 8).—Slide No. 432; Stage co-ordinates 37·0, 99·9; diameter 38 microns. Co-ordinates of lower right-hand corner of cover glass 46·8, 85·4.

Remarks.—The specific name is derived from the locality of the holotype, the Little West Moreton seam, intersected in Mines Department drillhole N.S. 183, in the Ipswich coalfield. It differs from the genotype *F. canalis* Balme in having denser ornamentation, the pits and channels being more closely packed than in Balme's species. Two species which have a somewhat similar type of ornamentation are *Lycopodium vermiculaesporites* Rouse 1957 and *L. cerniidites* Ross 1949, both described from the Cretaceous. However in the former the laesurae are significantly longer, reaching the periphery, while the latter species has a much thicker exine than the Bundamba specimens.

Foveosporites sp.

Plate 1, Figure 9

Description.—Amb sub-triangular to sub-circular. Diameter (based on 12 measured specimens) 28 to 46 microns. Trilete; laesurae, often inconspicuous or not evident, extending to equator. Exine ornamented by rounded pits and narrow channels, often branching. Width of pits and channels about 1·5 to 3 microns, intervening ridges about 3 to 4 microns. Ornament reduced on proximal face. Exine moderately thick, light brownish yellow to light brown.

Figured specimen (Plate 1, Figure 9).—Slide No. 387; Stage co-ordinates 33·1, 93·3; dimensions 35 x 33 microns. Co-ordinates of lower right-hand corner of cover glass 46·2, 87·0.

Remarks.—The specimens recorded here are characterised by a darker exine than *F. moretonensis* and a sculpture pattern not so dense as in that species, the pits and channels being more widely separated. They also appear to differ from *F. canalis* Balme in having a greater proportion of channel-like depressions, relative to rounded pits, than in that species. A new specific name has not been proposed because insufficient specimens are available to enable study of variation in diagnostic characters.

Genus ANNULISPORA de Jersey

Annulispora folliculosa (Rogalska) de Jersey

Remarks.—The specimens observed do not add to previous descriptions of this species (de Jersey 1959, p. 358; 1962, p. 5; 1963, p. 5). *A. folliculosa* is relatively rare in the samples examined from the Bundamba Group.

Annulispora microannulata de Jersey, Emend.

Plate 1, Figure 4

Emended diagnosis.—Amb sub-circular. Trilete, laesurae distinct, extending about two-thirds of the spore radius. Diameter (based on 20 measured specimens) 25 to 45 microns. Exine smooth or scabrate, 1·5 to 3 microns thick at equator. Distal portion of the spore wall with a sub-circular ring of thickened exine, average width 5 microns. Internal diameter of ring 2 to 4 microns, external diameter 8 to 17 microns.

Figured specimen (Plate 1, Figure 4).—Slide No. 318; Stage co-ordinates 32·0, 88·9; diameter 33 microns. Co-ordinates of lower right-hand corner of cover glass 47·4, 81·3.

Remarks.—The Bundamba specimens resemble in all features those previously described from the Ipswich Coal Measures, except that some of them have somewhat scabrate exines. Accordingly the writer's previous diagnosis (de Jersey 1962, p. 5) is emended to include them. A typical scabrate specimen is figured (plate 1, fig. 4).

Genus POLYCINGULATISPORITES (Simoncsics and Kedves) Playford and Dettmann

Polycingulatisporites densatus (de Jersey) Playford and Dettmann

Plate 1, Figures 10 and 11

Figured specimen (Plate 1, Figure 10).—Slide No. 352; Stage co-ordinates 34·0, 93·6; diameter 33 microns. Co-ordinates of lower right-hand corner of cover glass 47·3, 88·5.

Figured specimen (Plate 1, Figure 11).—Slide No. 350; Stage co-ordinates 34·0, 105·5; dimensions 23 x 26 microns. Co-ordinates of lower right-hand corner of cover glass 46·0, 89·3.

Remarks.—The taxonomy of this species has been studied by Playford and Dettmann (1964) who have discussed (*a*) the synonymy of *Polycingulatisporites* and (*b*) the reasons for incorporating the species in their emended version of that genus. Nothing can be added here to this comprehensive discussion. The species is rare in the Bundamba samples, but all the specimens, including those figured (Plate 1, Figs. 10 and 11) fall within the range of variation of the numerous specimens examined by Playford and Dettmann.

Genus DUPLEXISPORITES (Deák) Playford and Dettmann

Duplexisporites gyratus Playford and Dettmann

Plate 1, Figures 13, 14 and 15

Figured specimen (Plate 1, Figure 13).—Slide No. 324; Stage co-ordinates 37·9, 86·9; diameter 41 microns. Co-ordinates of lower right-hand corner of cover glass 45·1, 81·1.

Figured specimen (Plate 1, Figure 14).—Slide No. 318; Stage co-ordinates 38·9, 95·7; diameter 35 microns. Co-ordinates of lower right-hand corner of cover glass 47·5, 81·3.

Figured specimen (Plate 1, Figure 15).—Slide No. 350; Stage co-ordinates 30·05, 103·5; diameter 33 microns. Co-ordinates of lower right-hand corner of cover glass 46·1, 89·3.

Remarks.—The Bundamba specimens agree, in all essential features, with the diagnosis of Playford and Dettmann (1964). The presence of small specimens, for example, that illustrated in Plate 1, Fig. 15, suggests a slight extension of the size range given by those authors. This distinctive species persists through the Bundamba succession and has also been observed recently in samples from the Ipswich Coal Measures. The evidence available on the horizons of the samples concerned suggests that its range extends to, or almost to, the base of the Ipswich sequence.

Genus PUNCTATOSPORITES Ibrahim

Punctatosporites walkomi de Jersey

Diagnosis (de Jersey 1962, p. 6).—Amb circular, sub-circular or broadly oval. Monolete; laesura, often inconspicuous, extending from two-thirds to full length of spore. Diameter (based on 115 measured specimens) 20 to 38 microns. Exine about 1 micron thick, pale yellow to light brownish yellow, granulate, with projections 0·5 to 1 micron in diameter, about 40 along the equator. Sculpture pattern fairly dense, with projections 1 micron or less apart.

Remarks.—The Bundamba specimens resemble closely those previously described from the Ipswich Coal Measures.

Genus POLYPODIISPORITES Potonié and Gelletich ex Potonié

Polypodiisporites ipsviciensis (de Jersey) Playford and Dettmann

Plate 1, Figure 16

Description (Playford and Dettmann, 1964).—Microspores monolete, bilateral; plano-convex or biconvex in full equatorial view; amb broadly elliptical to sub-circular. Laesura straight, length two-thirds that of major equatorial axis. Exine comprehensively verrucate to verrucorugulate, 1-1·5 microns thick (excluding sculpture). Closely-spaced, rarely anastomosing verrucae and rugulae with irregular bases (2-10 microns maximum diameter), tapering sides (1-2 microns high), and rounded to pointed crests which are granulate to papillate.

Dimensions.—Equatorial diameter—length 22 (28) 36 microns, breadth 19 (25) 33 microns. Polar diameter (9 specimens)—19 (23) 26 microns.

Figured specimen (Plate 1, Figure 16).—Slide No. 413; Stage co-ordinates 43·1, 92·6; dimensions 30 x 23 microns. Co-ordinates of flower right-hand corner of cover glass 46·8, 85·7.

Remarks.—The recent transference of this species to *Polypodiisporites* by Playford and Dettmann is supported here. A full discussion of the taxonomy of the genus has been given by those authors (Playford and Dettmann, 1964). Plate 1, Fig. 16 illustrates a proximal view of a specimen with a well-defined monolete mark. The species ranges throughout the Bundamba sequence.

Genus TUBERCULATOSPORITES Imgrund

Tuberculatosporites aberdarensis, new species

Plate 1, Figures 17 and 18

Diagnosis.—Amb broadly oval to sub-circular. Length (based on 100 measured specimens) 17 to 36 microns. Monolete, where evident laesura extends length of spore, often inconspicuous or obscured by ornamentation. Exine ornamented with conical to spinose projections, with expanded bases, 1·5 to 3 microns in length, 1 to 1·5 microns in basal diameter, occasionally coalescing into rugulae, set about 1 micron apart. Exine light yellow, of medium thickness.

Holotype (Plate 1, Figure 17).—Slide No. 320; Stage co-ordinates 36·9, 89·6; dimensions 28 x 18 microns. Co-ordinates of lower right-hand corner of cover glass 47·8, 85·8.

Locality of holotype.—Mines Department drill-hole N.S. 201 (Ipswich coalfield), 982 ft. 2 in.

Paratype (Plate 1, Figure 18).—Slide No. 318; Stage co-ordinates 32·0, 88·9; dimensions 26 x 20 microns. Co-ordinates of lower right-hand corner of cover glass 47·4, 81·3.

Locality of paratype.—As above.

Remarks.—The specific name refers to the locality of the holotype, which came from a shale band within the Aberdare Conglomerate, at the base of the Bundamba Group. The species was abundant (19·4 per cent.) in this one sample, but rare or absent elsewhere in the sequence.

With regard to the generic affinities, two genera have been proposed for monolete spores with conical to spinose ornamentation. They are *Tuberculatosporites* Imgrund 1952 and *Spinosporites* Alpern 1958. The writer considers that the distinction between these genera, based on the distinctness of the monolete mark, shape and density of ornamentation, may be difficult to maintain and that such features are of specific, rather than generic, importance. The discovery of specimens intermediate between the two genera in these respects, as seems not unlikely, would favour regarding *Spinosporites* as a junior synonym of *Tuberculatosporites*. Accordingly, in anticipation of such a possibility, the Bundamba species has been placed in Imgrund's genus. It resembles *Tuberculatosporites* in outline; in density of ornamentation and distinctness of the monolete mark it is intermediate between type species of the two genera.

T. aberdarensis differs from *T. modicus* Balme and Hennelly, from the Australian Permian, in having projections which are more sharply spinose and less regular in shape. It differs from the genotype *T. anicystoides* Imgrund in having a denser sculpture pattern and a less distinct monolete mark. The spinose projections are less closely packed and less regular than in *Spinosporites spinosus* Alpern.

Division PTERIDOSPERMOPHYTA

Family CORYSTOSPERMACEAE

Genus ALISPORITES (Daugherty) Potonié and Kremp

Remarks.—*Alisporites* is used here, in the restricted sense of Potonié and Kremp (1956, pp. 176, 177) to include the dominant type of bisaccate pollen in the Bundamba Group. This is in agreement with the interpretation of Pocock (1962, pp. 60, 61). As stated by Pocock, Rouse's emendation (1959, p. 314) is slightly too restrictive, so that the interpretation of Potonié and Kremp is preferable. Pocock (1962, p. 60) and Jansonius (1962, p. 58) regard the indistinctness of the central body as a diagnostic feature. In the writer's opinion this is a questionable criterion as study of numerous specimens from the Triassic of Queensland suggests that this feature is influenced by the preservation and maceration technique. As illustrated by Daugherty (1941, pl. 34, fig. 2) the genotype *A. opii* has a reasonably distinct central body; well preserved specimens from the Queensland Triassic are similar to it in this feature. In *A. ovatus* (Balme and Hennelly) Jansonius, on the other hand, the central body is much less distinct, and its inclusion in *Alisporites* requires a broader interpretation of the genus than has been necessary for the Queensland material.

Alisporites australis de Jersey

Plate 2, Figure 1

Diagnosis (de Jersey 1962, pp. 8, 9).—Grains disaccate, total span (based on 64 measured specimens) 60 to 110 microns. Corpus longer than wide (polar view), ratio length to width greater than 5 to 4. Length of corpus 38 to 76 microns. Colpus (observed in well preserved, suitably oriented specimens) extending full length of corpus. Sacci not or scarcely overlapping on to proximal surface, roots of sacci markedly offset distally. Sacci as deep as corpus, or a little less. Ornament on sacci: brochi about 3 microns in diameter, muri about 1 micron wide. Ornament on corpus indistinct to faintly reticulate. Corpus and sacci without marked thickening, light yellow to brownish yellow, thickness about 1 to 1·5 microns.

Figured specimen (Plate 2, Figure 1).—Slide No. 353; Stage co-ordinates 38·1, 91·6; total span 81 microns. Co-ordinates of lower right-hand corner of cover glass 47·3, 82·8.

Remarks.—The specimens recorded here are similar to those previously described from the Ipswich Coal Measures. The species differs from those described by Pocock (1962) in the presence of a colpus in well preserved specimens, in the attachment of the sacci and the slightly greater distal inclination.

Alisporites spp.

Remarks.—Under this heading are recorded pollen grains which, because of poor preservation or morphological differences, could not be included in *A. australis*. Poor preservation, unfavourable presentation and continuous variation in possible diagnostic characters have prevented any grouping of these specimens into distinct species.

Family CAYTONIACEAE

Genus VITREISPORITES (Leschik) Jansonius, Emend.

Emended diagnosis.—Bisaccate grains, central body sub-circular, bladders with fine reticulation, faintly roughened, or smooth, proximally attached at equator, distally reaching almost to distal pole leaving a narrow straight germinal area uncovered, distal bladder base distinct; proximal face without infrareticulate exoexine: whole spore characteristically pale and thin walled, but proximal bladder base often with some folding, size small for a bisaccate pollen.

Type species.—*Vitreisporites signatus* Leschik (Leschik 1956, p. 53).

Remarks.—The diagnosis of Jansonius (1962, p. 55) is here emended to allow for the inclusion of grains with little, if any, ornamentation on the bladders, which otherwise have all the essential diagnostic features of the genus. The new species, *V. microsaccus*, described below, includes grains of this type.

Vitreisporites microsaccus, new species

Plate 2, Figures 3, 4 and 5

Diagnosis.—Pollen grains bisaccate. Total span (based on 36 measured specimens) 21 to 35 microns. Corpus (central body) sub-circular or broadly oval (broader than long or longer than broad) diameter 16 to 21 mircons, exine smooth, very thin (less than 1 micron). Sacci (bladders) attached proximally at equator or with slight proximal overlap (3 to 5 microns), distally reaching almost to distal pole; free portion of sacci crescent-shaped, relatively short (width about half diameter of corpus or even less). Sacci attached with slight to distinct distal inclination. Exine of sacci smooth, or rarely with very faint (? subreticulate) ornament, pale yellow, relatively thin (less than 1 micron).

Holotype (Plate 2, Figure 5).—Slide No. 411; Stage co-ordinates 37·8, 92·9; total span 25 microns. Co-ordinates of lower right-hand corner of cover glass 47·0, 82·0.

Locality of holotype.—Mines Department drillhole N.S. 201 (Ipswich Coalfield), 313 ft. 7 in. (Ripley Road Sandstone).

Figured specimen (Plate 2, Figure 4).—Slide No. 414; Stage co-ordinates 35·9, 103·9; total span 23 microns. Co-ordinates of lower right-hand corner of cover glass 46·0, 87·6.

Figured specimen (Plate 2, Figure 3).—Slide No. 407; Stage co-ordinates 38·1, 88·7; total span 21 microns. Co-ordinates of lower right-hand corner of cover glass 46·1, and 81·8.

Remarks.—The smooth, or only faintly ornamented nature of the sacci appears to be an original feature in this species, and not the result of overmaceration. Accordingly the generic diagnosis has been emended to allow for the inclusion of such grains, which agree with the definition of Jansonius in other features. Apart from this lack of marked saccus ornament, the most distinctive feature is the small size of the bladders, which do not project far beyond the central body. This characteristic (to which the specific name alludes), together with the distal inclination of the bladders, distinguishes *V. microsaccus* from previously described species of *Vitreisporites.*

Monocolpate Pollen Grains

Genus CYCADOPITES (Wodehouse) Wilson and Webster

Remarks.—Jansonius (1962, p. 80) regarded *Ginkgocycadophytus* Samoilovitch 1953 as a synonym of *Cycadopites* (Wodehouse 1933) Wilson and Webster 1946. This opinion is supported here, and necessitates transferring to *Cycadopites* species previously placed by the writer in *Ginkgocycadophytus* (de Jersey 1962, pp. 12, 13).

Cycadopites nitidus (Balme), new combination

Selected synonymy

1957. *Entylissa nitidus* Balme, C.S.I.R.O. Fuel Research T.C. **25**, p. 30, pl. 6, figs. 78-80.

1962. *Ginkgocycadophytus nitidus* (Balme) de Jersey, Geol. Surv. Qld Publ., **307**, 12, pl. 5, figs. 1, 2 and 3.

Description (de Jersey 1962, p. 12).—Amb elongated oval to broadly oval. Monocolpate, furrow extending full length of the distal surface, uniform in width or slightly expanded at the extremities. Length (based on 145 measured specimens) 20 to 25 microns, breadth 11 to 36 microns. Exine smooth or faintly scabrate, 1 micron or less in thickness.

Remarks.—Specimens of *C. nitidus* are fairly common in most samples from the Bundamba Group. They resemble in all particulars those previously described from the Ipswich Coal Measures (de Jersey 1962, p. 12).

Cycadopites granulatus (de Jersey), new combination

1962. *Ginkgocycadophytus granulatus* de Jersey, Geol. Surv. Qld Publ. **307**, p. 12, pl. 5, 5, figs. 5, 6 and 7.

Diagnosis (de Jersey 1962, p. 12).—Amb elongated oval. Monocolpate furrow extending full length of distal surface, often expanded at extremities. Length (based on 30 measured specimens) 24 to 55 microns, width 14 to 28 microns. Exine about 1 micron thick, light yellow. Ornamentation dominantly granulate, with rounded projections 0·5 to 1 micron in diameter, to papillate. Sculpture pattern fairly dense, with projections 1 micron or less apart.

Remarks.—The specimens of *C. granulatus* from the Bundamba Group are quite similar to those previously described from the Ipswich Coal Measures.

Cycadopites crassimarginis (de Jersey), new combination

1959. *Entylissa crassimarginis* de Jersey, Qld Govt Min. J., **60**, 361, pl. 2, figs. 15 16.

1962. *Ginkgocycadophytus crassimarginis* (de Jersey) de Jersey, Geol. Surv. Qld Publ. **307**, 12, pl. 5, fig. 4.

Diagnosis (de Jersey 1959, p. 36).—Amb elongated oval. Monocolpate furrow extending full length of the distal surface, each furrow margin thickened for an average width of about 3 microns. Length (based on 63 measured specimens) 20 to 45 microns, width 10 to 31 microns. Exine smooth, 1 micron or less in thickness.

Remarks.—*C. crassimarginis* resembles, in the presence of thickened furrow margins, specimens recorded by Jansonius (1962, p. 80) as *Cycadopites* cf. *C. follicularis* Wilson and Webster. However, Wilson and Webster do not mention the presence of this feature in the original description (1946, p. 274)

and from their illustration it is not clear whether the appearance of thickening is due to folding along the furrow margins. Consequently the species are provisionally regarded as distinct. *C. crassimarginis* is relatively rare in samples from the Bundamba Group.

Division CONIFEROPHYTA

Family ARAUCARIACEAE

Genus ARAUCARIACITES (Cookson) Couper

Araucariacites sp.

Remarks.—The specimens recorded here are similar to those previously described and figured from the Marburg Sandstone (de Jersey 1963, p. 8, pl. 2, fig. 3) and from the Ipswich Coal Measures (de Jersey 1962, p. 13, pl. 5, fig. 11). They differ from the grains described by Cookson (1947, p. 130) and Couper (1958, p. 151) in having a coarser granulate-papillate ornament. Insufficient well preserved specimens have been found in the Bundamba samples to enable detailed morphological studies. The Bundamba specimens range in diameter from 45 to 80 microns.

Division CONIFEROPHYTA

Genus INAPERTUROPOLLENITES Thomson and Pflug

Remarks.—Manum (1962, pp. 17, 39) has discussed the taxonomy of *Inaperturopollenites* and *Laricoidites*. He has clearly demonstrated (a) that *Laricoidites* is only poorly distinguished from *Inaperturopollenites* and (b) that *Inaperturopollenites* has chronological priority over *Laricoidites*, not vice versa, as claimed by Potonié. The writer is in agreement with Manum's conclusions, as pollen grains of this type do not show sufficient variation to warrant use of two separate generic names. Consequently the species which the writer, following Potonié, transferred to *Laricoidites reidi* (de Jersey 1962, p. 13) is here restored to its original combination, *Inaperturopollenites reidi*.

Inaperturopollenites reidi de Jersey

1959. *Inaperturopollenites reidi* de Jersey. Qld Govt Min. J. **60**, 362, pl. 3, fig. 7.

1962. *Laricoidites reidi* (de Jersey) de Jersey. Geol. Surv. Qld Publ. **307**, 313, pl. 6, fig. 6.

1963. *Laricoidites reidi* (de Jersey) de Jersey. Geol. Surv. Qld Publ. **313**, 8, 9.

Diagnosis (de Jersey 1959, p. 362).—Outline circular or sub-circular, frequently distorted by folding. Diameter (based on 156 measured specimens) 60 to 112 microns (average about 82 microns). Exine smooth, thin (about 1 micron in thickness), frequently folded, light brownish yellow to almost colourless.

Remarks.—The specimens recorded here are similar to those previously described from the Ipswich and Walloon Coal Measures. The species is relatively rare in the Bundamba Group, as it is in the underlying Ipswich Coal Measures.

Bisaccate Pollen Grains (Incertae Sedis)

Genus PLATYSACCUS (Naumova) Potonié and Klaus

Platysaccus queenslandi de Jersey

Plate 2, Figure 2

Figured specimen (Plate 2, Figure 2).—Slide No. 349; Stage co-ordinates 33·9, 97·0; total span 76 microns. Co-ordinates of lower right-hand corner of cover glass 46·6, 84·4.

Remarks.—The Bundamba specimens of this species agree in all diagnostic characters with those described from the Ipswich Coal Measures (de Jersey 1962, p. 10).

Genus CHORDASPORITES Klaus

Chordasporites sp.

Remarks.—As only six poorly preserved specimens of this genus have been observed specific determination has not been attempted. The size range (total span 49 to 82 microns) differs somewhat from that of *C. australiensis* from the Ipswich Coal Measures although in general the other features are similar.

? Division CONIFEROPHYTA

Remarks.—Under this heading are recorded genera which Klaus (1960, p. 159) has placed in the *Subturma Circumpolles* of Potonié's morphological classification. As Couper (1958, p. 157) has brought forward evidence for the Coniferous affinity of *Classopollis*, a genus in the same supra-generic group, a possible Coniferous affinity is indicated for the genera recorded below, on the basis of morphological similarity.

Genus DUPLICISPORITES (Leschik) Klaus

Duplicisporites granulatus Leschik

Description (based on Bundamba specimens).—Amb rounded sub-triangular. Diameter (based on 12 measured specimens) 34 to 50 microns. No trilete mark observed. Three prominent folds or ridges on distal surface, near equator, parallel to equatorial margin, width 4 to 13 microns. Exine granulate, with closely packed projections 1 micron in average diameter. Exine thinner around distal pole.

Remarks.—The specimens recorded agree closely with the descriptions and figures of Leschik (1955, p. 23; pl. 2, fig. 23) and Klaus (1960, p. 161; pl. 5, fig. 53), who have studied the species in the Upper Triassic of Europe. Jansonius (1962, p. 49) has compared specimens from the Lower Triassic (Scythian) of Canada with this species. He regards the three prominent ridges as proximal, not distal as indicated by Klaus. Of these alternative interpretations, the writer favours that of Klaus (1960, p. 161), which is supported by the presence of a vestigial trilete mark in specimens described by both Klaus and Leschik. A vestigial trilete mark has also been observed by the

writer in a specimen of the species from the Ipswich Coal Measures. This specimen came from sediments in the Brisbane area, correlated with the lower part of the Ipswich sequence. Another specimen, from the Tivoli Formation, in the type area of the Ipswich Coal Measures is illustrated (Pl. 2, Fig. 12). It has folds closer to the equator and somewhat coarser sculpture than *D. granulatus* and is recorded as *Duplicisporites* sp.

Genus PARTITISPORITES Leschik

Partitisporites novimundanus Leschik

Plate 2, Figures 6 and 7

Description (based on Bundamba specimens).—Exine consisting of two portions, of oval to sub-circular outline, originally attached to each other approximately at right angles. Maximum diameter (based on 12 measured specimens) 24 to 49 microns; maximum diameter of each portion 18 to 49 microns. Vestigial trilete mark with short laesurae, usually on one portion of exine. Exine finely granulate (projections about 1 micron and fairly closely packed), light yellow to brownish yellow.

Figured specimen (Plate 2, Figure 6).—Slide No. 318; Stage co-ordinates 34·7, 85·9; dimensions 33 x 31 microns. Co-ordinates of lower right-hand corner of cover glass 47·5, 81·3.

Figured specimen (Plate 2, Figure 7).—Slide No. 353; Stage co-ordinates 40·05, 89·9; dimensions 49 x 38 microns. Co-ordinates of lower right-hand corner of cover glass 47·3, 82·7.

Remarks.—The Bundamba specimens agree closely with Leschik's description and figures (Leschik 1955, p. 54; pl. 2, figs. 24-26, pl. 3, figs. 1-3). Klaus (1960, p. 164) has also recorded the species from the Upper Triassic (Karnian) of Austria. The writer is indebted to Dr. Klaus for confirming the identification of the specimens figured in pl. 2, figs. 6 and 7 (Personal communication dated 12/2/64).

Genus DISCISPORITES Leschik, Emend.

Emended diagnosis.—Amb circular or sub-circular. Triradiate trilete mark, distinct to inconspicuous. Narrow circular band of thinner exine (ring-tenuitas or rimula) on distal face. Sculpture pattern various, including smooth, scabrate, granulate, verrucose and striate ornamentation.

Type species.—*Discisporites niger* Leschik (Leschik 1955, p. 26, pl. 3, fig. 12).

Remarks.—Leschik's diagnosis is here emended so as to stress the essential generic features as indicated by Klaus (1960, pp. 159, 160), namely (1) the presence of a triradiate trilete mark with narrow closed laesurae (not a dehiscence triangle) and (2) the presence of a distal ring-tenuitas or rimula. The position of the latter relative to the equator is regarded as a specific, not a generic character; it may be close to the equator, as in *D. psilatus* and *D. verrucosus*, described below, or about half-way between the equator and distal pole as in *D. niger* Leschik. Provision is also made for variety in ornamentation. It is considered that widening the scope of the genus will make it more useful in recording species such as those described below, which agree, in fundamental generic characters, with the type species.

Discisporites psilatus, new species

Plate 2, Figures 9 and 11

Diagnosis.—Amb sub-triangular to circular. Diameter (based on 10 measured specimens) 25 to 36 microns. Vestigial trilete mark; narrow closed laesurae with length about two-thirds spore radius. Narrow ring of thinner exine (ring-tenuitas or rimula) 2 to 5 microns in from equator on distal surface. Thinning of distal exine, observed in well preserved specimens, extending from distal pole almost to ring tenuitas. Exine smooth or scabrate, light yellow to light brown.

Holotype (Plate 2, Figure 9).—Slide No. 392; Stage co-ordinates 37·9, 100·2; diameter 26 microns. Co-ordinates of lower right-hand corner of cover glass 45·9, 89·1.

Locality of holotype.—Mines Department drill-hole N.S. 201 (Ipswich coalfield), 540 ft. 4 in.

Figured specimen (Plate 2, Figure 11).—Slide No. 424; Stage co-ordinates 42·0, 83·0; diameter 33 microns. Co-ordinates of lower right-hand corner of cover glass 47·0, 82·0.

Remarks.—The specific name refers to the typical smooth (or faintly ornamented) nature of the exine. Placing of this species in *Discisporites* is based on the presence of a vestigial trilete mark (not a dehiscence triangle as in *Circulina*) and on the presence of a rimula or ring-tenuitas. It differs from *D. niger* Leschik in the position of the ring-tenuitas, which is much closer to the equator than in that species. The lack of pronounced ornamentation provides a distinction from *D. striatus* Leschik (Leschik 1959, p. 55) and from *D. verrucosus*, n.sp., described below.

Discisporites verrucosus, new species

Plate 2, Figures 13, 15 and 16

Diagnosis.—Amb rounded sub-triangular to circular. Diameter (based on 110 measured specimens) 21 to 43 microns (mean about 30 microns). Weak vestigal trilete mark (narrow closed laesurae) observed in some specimens. Exine differentiated into a central portion and an equatorial zone. Equatorial zone 2 to 5 microns in width, smooth or with a few scattered projections. Remainder of distal surface granulate to verrucose, with closely packed rounded projections 1·5 to 4 microns in diameter. Narrow ring of thinner exine (ring-tenuitas or rimula) evident on distal surface at inner margin of equatorial zone in well preserved specimens. Remainder of proximal surface smooth or with reduced ornament. Exine light to dark brown (equatorial zone) to light yellow (central portion).

Holotype (Plate 2, Figure 15).—Slide No. 371; Stage co-ordinates 31·0, 97·8; diameter 35 microns. Co-ordinates of lower right-hand corner of cover glass 48·0, 88·8.

Locality of holotype.—Mines Department drill-hole N.S. 201 (Ipswich coalfield), 718 ft. 7 in.

Figured specimen (Plate 2, Figure 16).—Slide No. 320; Stage co-ordinates 46·1, 94·8; dimensions 33 x 26 microns. Co-ordinates of lower right-hand corner of cover glass 47·8, 85·8.

Remarks.—The specific name refers to the verrucose ornament of this species. Study of well preserved specimens indicates the presence of both a rimula (ring-tenuitas) and a vestigial trilete mark. The former is often obscured by the ornamentation, but is visible in one of the specimens figured (Plate 2, Figure 13); this shows a well preserved specimen obliquely compressed. The vestigial trilete mark is also frequently poorly defined or obscured by the ornamentation, but is visible in another figured specimen (Plate 2, Figure 16). These features provide grounds for placing the species in *Discisporites* as defined above; its verrucose ornament and darker equatorial zone distinguish it from other described species of the genus.

Genus CIRCULINA Maljawkina

Remarks.—The discovery of this European genus in the Bundamba Group is of considerable importance in correlation of the Triassic of the two areas. The appearance of *Circulina* represents a significant stage in the evolution of pollen grains of the *Circumpolles* type, as it marks the first appearance of the combination of a distal ring-tenuitas and a proximal dehiscence triangle. From the stratigraphic aspect, the first appearance of this evolutionary stage in the Karnian of Europe and its earliest occurrence near the base of the Bundamba Group, in Queensland, are thus regarded as approximately contemporaneous.

Circulina meyeriana Klaus

Plate 2, Figure 10

Description (based on Bundamba specimens).—Amb circular or sub-circular. Diameter (based on 20 measured specimens) 24 to 38 microns, mean 30 microns. Narrow ring-tenuitas (band of thinner exine) about 1 micron in width, 2·5 to 5 microns in from equator on distal surface. Proximal dehiscence triangle with straight or slightly concave sides, 5 to 11 microns in length (approximately ½ radius of exine). Area of distal polar thinning (distal tenuitas) of sub-circular outline, diameter equal to or slightly less than radius of exine. Exine smooth to faintly scabrate, light yellow to light brown in transmitted light.

Figured specimen (Plate 2, Figure 10).—Slide No. 369; Stage co-ordinates 39·9, 97·3; diameter 28 microns. Co-ordinates of lower right-hand corner of cover glass 46·1, 94·2.

Remarks.—The identification of the specimen figured (Plate 2, Figure 10) has been confirmed by Dr. W. Klaus (Personal communication dated February 12th, 1964). The Bundamba specimens are generally similar to *C. meyeriana*; slight differences exist in their tendency to have a slightly smaller dehiscence triangle and slightly larger distal tenuitas than those figured by Klaus (1960, pl. 36, figs. 57–60), but these differences are within the range of variation of the Austrian material.

Circulina sp. 1

Plate 2, Figures 14 and 17

Figured specimen (Plate 2, Figure 14).—Slide No. 342; Stage co-ordinates 39·9, 88·0; dimensions 38 x 30 microns. Co-ordinates of lower right-hand corner of cover glass 46·8, 84·5.

Figured specimen (Plate 2, Figure 17).—Slide No. 369; Stage co-ordinates 33·9, 94·8; dimensions 38 x 33 microns. Co-ordinates of lower right-hand corner of cover glass 46·1, 94·2.

Remarks.—Specimens of this species differ from *C. meyeriana* in having an appreciably larger dehiscence triangle (Pl. 2, fig. 14) and a larger distal tenuitas (Pl. 2, fig. 17). The species is less abundant in the Bundamba samples than *C. meyeriana*, and insufficient well preserved specimens have been observed to warrant use of a new specific name. However, it is of interest to note that specimens of the same species have been observed in the Triassic of Austria, where it is restricted to the Karnian (Personal communication from Dr. Klaus, dated February 12th, 1964).

cf. *Circulina* sp.

Plate 1, Figure 12

Figured specimen (Plate 1, Figure 12).—Slide No. 369; Stage co-ordinates 44·1, 105·1; diameter 33 microns. Co-ordinates of lower right-hand corner of cover glass 46·2, 94·2.

Remarks.—Poorly prescribed specimens of the type illustrated in Pl. 1, Fig. 12 are recorded under this heading. They are compared with *Circulina* because of the presence of vague indications of a ring-tenuitas and proximal dehiscence triangle in some of them, but others could equally well represent specimens of *Discisporites psilatus*, lacking the vestigial trilete mark, or of *D. verrucosus*, with the distal face torn out.

Spores and Pollen Grains (Incertae Sedis)

Genus CIRCULISPORITES de Jersey

Circulisporites parvus de Jersey

Remarks.—Specimens of this species in the Bundamba samples are similar in all respects to those previously described from the Ipswich Coal Measures (de Jersey 1962, p. 15). With the exception of a coal sample from the Little West Moreton seam, in which it reaches a proportion of 10 per cent., *C. parvus* is relatively rare in most samples from the Bundamba Group.

VI. MICROFLORAL ASSEMBLAGES

Lists of microfloral assemblages recorded, with percentages of the species, are given below in ascending stratigraphic order.

(a) Aberdare Conglomerate

Bore N.S. 201, 1,027 ft. 11 in.

Lithology.—Carbonaceous shale.

Specimens examined.—500.

Alisporites australis	0·6%
Alisporites spp.	1·6%
Annulispora folliculosa	0·2%
Chordasporites sp.	0·2%
Circulisporites parvus	0·2%
Converrucosisporites cameroni	0·4%
Cycadopites granulatus	0·2%
C. nitidus	4·2%
Dictyophyllidites mortoni	0·2%
Duplexisporites gyratus	0·2%
Inapertisporites minutus	1·0%
Leiotriletes directus	0·6%
Leiotriletes spp.	2·2%
Polypodiisporites ipsviciensis	9·2%
Punctatosporites walkomi	74·0%
Indeterminate	5·0%

Bore N.S. 201, 982 ft. 2 in.

Lithology.—Carbonaceous shale.

Specimens examined.—500.

Alisporites australis	1·2%
Alisporites spp.	2·4%
Annulispora folliculosa	0·2%
A. microannulata	0·4%
Araucariacites sp.	1·0%
Chordasporites sp.	0·2%
Circulina meyeriana	0·2%
cf. *Circulina* sp.	1·8%
Circulisporites parvus	2·0%
Cycadopites granulatus	0·2%
C. nitidus	3·6%
Dictyophyllidites mortoni	0·2%
Discisporites verrucosus	6·8%
Duplexisporites gyratus	0·4%
Granulatisporites minor	3·4%
Inapertisporites crassus	0·4%
I. minutus	0·2%
Leiotriletes directus	1·2%
Leiotriletes spp.	6·2%
Osmundacidites wellmanii	2·0%
Partitisporites novimundanus	1·2%
Polycingulatisporites densatus	0·2%
Polypodiisporites ipsviciensis	0·8%
Punctatisporites sp.	0·8%
Punctatosporites walkomi	21·0%
Tuberculatosporites aberdarensis	19·4%
Verrucosisporites sp.	0·4%
Vitreisporites sp.	0·2%
Indeterminate	20·8%

Bore N.S. 201, 958 ft. 7 in.

Lithology.—Carbonaceous shale.

Specimens examined.—500.

Alisporites australis	0·8%
Alisporites spp.	3·6%
Annulispora folliculosa	0·2%
A. microannulata	0·8%
Araucariacites sp.	0·4%
Circulina meyeriana	0·2%
cf. *Circulina* sp.	1·4%
Converrucosisporites cameroni	0·4%
Converrucosisporites sp.	0·4%
Cycadopites crassimarginis	0·2%
C. granulatus	0·8%
C. nitidus	0·6%
Dictyophyllidites mortoni	3·0%
Discisporites verrucosus	5·8%
Duplexisporites gyratus	3·4%
Duplicisporites granulatus	0·4%
Foveosporites moretonensis	0·4%
Foveosporites sp.	2·2%
Granulatisporites minor	6·6%
Inaperturopollenites reidi	0·4%
Leiotriletes directus	30·8%
Leiotriletes spp.	6·8%
Lycopodiumsporites antiquus	0·6%
Osmundacidites wellmanii	3·0%
Partitisporites novimundanus	0·4%
Polypodiisporites ipsviciensis	1·0%
Punctatisporites sp.	0·6%
Punctatosporites walkomi	1·4%
Stereisporites antiquasporites	0·4%
S. tenuis	0·2%
Tuberculatosporites aberdarensis	0·2%
Vitreisporites sp.	0·2%
Indeterminate	22·4%

(b) Raceview Formation

Bore N.S. 201, 923 ft.

Lithology.—Carbonaceous shale.

Specimens examined.—200.

Alisporites australis	4·5%
Alisporites spp.	27·5%
Annulispora folliculosa	0·5%
Araucariacites sp.	1·0%
cf. *Circulina* sp.	0·5%
Circulisporites parvus	1·0%
Cycadopites granulatus	0·5%
C. nitidus	12·0%
Duplexisporites gyratus	1·0%
Granulatisporites minor	4·5%
Inapertisporites crassus	5·0%
I. minutus	0·5%
Leiotriletes directus	22·5%
Leiotriletes spp.	1·5%
Osmundacidites wellmanii	1·0%
Polypodiisporites ipsviciensis	0·5%
Punctatosporites walkomi	2·5%
Indeterminate	11·0%

Bore N.S. 201, 892 ft. 10 in.
Lithology.—Coal.
Specimens examined.—200.

Alisporites australis	1·0%
Alisporites spp.	3·5%
Circulina sp. 1	0·5%
Cycadopites granulatus	2·0%
C. nitidus	11·5%
Duplicisporites granulatus	1·0%
Granulatisporites minor	13·0%
Inapertisporites crassus	2·0%
I. minutus	1·5%
Inaperturopollenites reidi	0·5%
Leiotriletes directus	32·5%
Leiotriletes spp.	6·5%
Osmundacidites wellmanii	1·5%
Osmundacidites sp.	1·5%
Partitisporites novimundanus	0·5%
Punctatisporites sp.	1·0%
Stereisporites antiquasporites	0·5%
S. tenuis	1·5%
Indeterminate	18·0%

Bore N.S. 201, 842 ft. 3 in.
Lithology.—Carbonaceous shale.
Specimens examined.—500.

Alisporites australis	16·0%
Alisporites spp.	35·4%
Annulispora folliculosa	0·4%
Araucariacites sp.	0·8%
cf. *Circulina* sp.	0·8%
Converrucosisporites sp.	0·2%
Cycadopites nitidus	9·8%
Dictyophyllidites mortoni	0·2%
Discisporites verrucosus	0·8%
Duplexisporites gyratus	2·6%
Foveosporites moretonensis	0·2%
Granulatisporites minor	7·8%
Inaperturopollenites reidi	0·2%
Inapertisporites crassus	0·2%
Leiotriletes directus	10·2%
Leiotriletes spp.	2·2%
Lycopodiumsporites antiquus	0·4%
Osmundacidites wellmanii	1·8%
Partitisporites novimundanus	0·2%
Platysaccus queenslandi	0·2%
Polycingulatisporites densatus	0·2%
Polypodiisporites ipsviciensis	0·2%
Indeterminate	19·0%

Bore N.S. 201, 821 ft. 8 in.
Lithology.—Carbonaceous shale.
Specimens examined.—500.

Alisporites australis	9·4%
Alisporites spp.	32·8%
Araucariacites sp.	0·4%
Chordasporites sp.	0·2%
Circulina meyeriana	0·6%
cf. *Circulina* sp.	0·4%
Converrucosisporites sp.	0·2%
Cycadopites granulatus	0·2%
C. nitidus	3·2%
Dictyophyllidites mortoni	0·8%
Discisporites psilatus	0·4%
D. verrucosus	4·0%
Duplexisporites gyratus	0·8%
Foveosporites sp.	0·2%
Granulatisporites minor	2·4%
Inapertisporites minutus	0·4%
I. crassus	1·4%
Inaperturopollenites reidi	0·6%
Leiotriletes directus	15·0%
Leiotriletes spp.	3·8%
Osmundacidites wellmanii	1·4%
Partitisporites novimundanus	0·2%
Polypodiisporites ipsviciensis	1·4%
Punctatisporites sp.	0·6%
Punctatosporites walkomi	0·6%
Stereisporites tenuis	0·2%
Vitreisporites microsaccus	0·2%
Indeterminate	18·4%

Bore N.S. 183, 851 ft. 7¼ in. to 854 ft.
Lithology.—Coal (Little West Moreton seam).
Specimens examined.—200.

Alisporites australis	1·5%
Alisporites spp.	14·0%
Annulispora folliculosa	2·5%
A. microannulata	2·0%
Circulisporites parvus	10·0%
Cycadopites nitidus	2·0%
Dictyophyllidites mortoni	0·5%
Discisporites verrucosus	0·5%
Foveosporites moretonensis	2·5%
Granulatisporites minor	6·5%
Inapertisporites crassus	0·5%
I. minutus	0·5%
Inaperturopollenites reidi	0·5%
Leiotriletes directus	6·0%
Leiotriletes spp.	2·5%
Osmundacidites wellmanii	0·5%
Punctatisporites sp.	1·0%
Stereisporites antiquasporites	30·5%
S. tenuis	1·0%
Indeterminate	15·0%

Bore N.S. 201, 789 ft. 8 in.
Lithology.—Carbonaceous shale.
Specimens examined.—500.

Alisporites australis	9·4%
Alisporites spp.	56·8%
cf. *Circulina* sp.	0·4%
Converrucosisporites sp.	0·4%
Cycadopites nitidus	3·8%
Dictyophyllidites mortoni	0·2%
Discisporites verrucosus	0·2%
Duplexisporites gyratus	0·8%
Duplicisporites granulatus	0·6%
Foveosporites sp.	0·2%
Granulatisporites minor	3·0%
Leiotriletes directus	9·0%
Leiotriletes spp.	28·0%
Lycopodiumsporites antiquus	0·2%
Osmundacidites wellmanii	1·0%
Polypodiisporites ipsviciensis	1·8%
Punctatisporites sp.	0·2%
Vitreisporites sp.	0·2%
Indeterminate	10·0%

Bore N.S. 201, 718 ft. 7 in.
Lithology.—Carbonaceous siltstone.
Specimens examined.—500.

Alisporites australis	5·2%
Alisporites spp.	30·4%
Araucariacites sp.	0·2%
Circulina meyeriana	0·4%
Circulina sp. 1	0·2%
cf. *Circulina* sp.	1·6%
Converrucosisporites cameroni	0·2%
Cycadopites nitidus	1·8%
Dictyophyllidites mortoni	0·4%
Discisporites verrucosus	2·0%
Duplexisporites gyratus	1·8%
Duplicisporites granulatus	0·2%
Foveosporites moretonensis	1·2%
Foveosporites sp.	1·0%
Granulatisporites minor	6·8%
Inaperturopollenites reidi	0·2%
Leiotriletes directus	16·8%
Leiotriletes spp.	2·6%
Lycopodiumsporites antiquus	6·8%
Osmundacidites wellmanii	1·6%
Partitisporites novimundanus	0·2%
Polypodiisporites ipsviciensis	0·2%
Punctatisporites sp.	0·6%
Stereisporites tenuis	0·6%
Vitreisporites sp.	0·4%
Indeterminate	16·6%

Bore N.S. 201, 685 ft. 3 in.
Lithology.—Carbonaceous shale.
Specimens examined.—500.

Alisporites australis	4·6%
Alisporites spp.	54·8%
Circulina meyeriana	0·4%
cf. *Circulina* sp.	0·4%
Circulisporites parvus	0·2%
Converrucosisporites sp.	0·6%
Cycadopites nitidus	3·2%
Dictyophyllidites mortoni	0·2%
Duplexisporites gyratus	1·6%
Granulatisporites minor	4·0%
Leiotriletes directus	7·4%
Leiotriletes spp.	1·2%
Lycopodiumsporites antiquus	0·2%
Osmundacidites wellmanii	2·0%
Platysaccus queenslandi	0·2%
Polypodiisporites ipsviciensis	7·4%
Stereisporites tenuis	0·2%
Verrucosisporites sp.	0·4%
Indeterminate	11·0%

Bore N.S. 201, 632 ft. 6 in.
Lithology.—Carbonaceous shale.
Specimens examined.—500.

Alisporites australis	9·0%
Alisporites spp.	44·6%
Annulispora folliculosa	0·2%
Araucariacites sp.	0·2%
Converrucosisporites cameroni	0·4%
Cycadopites nitidus	3·0%
Discisporites verrucosus	0·2%
Duplexisporites gyratus	1·0%
Granulatisporites minor	4·8%
Inaperturopollenites reidi	0·2%
Leiotriletes directus	5·2%
Leiotriletes spp.	2·2%
Osmundacidites wellmanii	0·8%
Platysaccus queenslandi	0·4%
Polypodiisporites ipsviciensis	12·8%
Vitreisporites microsaccus	2·6%
Vitreisporites sp.	2·2%
Indeterminate	10·2%

Bore N.S. 201, 585 ft.
Lithology.—Carbonaceous shale.
Specimens examined.—200.

Alisporites australis	7·0%
Alisporites spp.	52·0%
cf. *Circulina* sp.	1·0%
Cycadopites nitidus	4·5%
Dictyophyllidites mortoni	0·5%
Discisporites psilatus	0·5%
D. verrucosus	0·5%
Duplexisporites gyratus	2·0%
Foveosporites moretonensis	0·5%
Granulatisporites minor	6·5%
Inaperturopollenites reidi	0·5%
Leiotriletes directus	8·5%
Leiotriletes spp.	3·0%
Lycopodiumsporites antiquus	0·5%
Osmundacidites wellmanii	3·0%
Platysaccus queenslandi	0·5%
Polypodiisporites ipsviciensis	1·0%
Stereisporites tenuis	0·5%
Indeterminate	7·5%

Bore N.S. 201, 578 ft. 5 in.
Lithology.—Coal.
Specimens examined.—500.

Alisporites australis	3·0%
Alisporites spp.	20·4%
Annulispora microannulata	0·2%
Araucariacites sp.	1·2%
Cycadopites crassimarginis	0·2%
C. nitidus	24·8%
Dictyophyllidites mortoni	0·2%
Granulatisporites minor	0·8%
Inapertisporites minutus	0·2%
Inaperturopollenites reidi	0·4%
Leiotriletes directus	8·2%
Leiotriletes spp.	1·8%
Osmundacidites wellmanii	0·4%
Osmundacidites sp.	5·8%
Polypodiisporites ipsviciensis	16·8%
Punctatisporites sp.	0·8%
Verrucosisporites sp.	0·6%
Vitreisporites microsaccus	1·2%
Vitreisporites sp.	1·2%
Indeterminate	11·8%

Bore N.S. 201, 540 ft. 4 in.
Lithology.—Shale.
Specimens examined.—500.

Alisporites australis	4·0%
Alisporites spp.	35·2%
Annulispora microannulata	0·2%
Araucariacites sp.	1·2%
cf. *Circulina* sp.	1·6%
Cycadopites crassimarginis	0·2%
C. granulatus	0·2%
C. nitidus	5·6%
Discisporites psilatus	0·6%
D. verrucosus	1·4%
Duplexisporites gyratus	0·4%
Foveosporites moretonensis	0·4%
Foveosporites sp.	1·4%
Granulatisporites minor	4·2%
Inapertisporites crassus	0·6%
I. minutus	0·4%
Leiotriletes directus	15·4%
Leiotriletes spp.	3·4%
Lycopodiumsporites antiquus	7·8%
Osmundacidites wellmanii	0·6%
Polypodiisporites ipsviciensis	0·6%
Stereisporites tenuis	0·4%
Verrucosisporites sp.	0·2%
Indeterminate	14·0%

(c) Ripley Road Sandstone

Bore N.S. 201, 432 ft. 9 in.
Lithology.—Siltstone.
Specimens examined.—200.

Alisporites australis	6·5%
Alisporites spp.	51·0%
cf. *Circulina* sp.	0·5%
Cycadopites nitidus	15·5%
Dictyophyllidites mortoni	0·5%
Discisporites verrucosus	0·5%
Granulatisporites minor	1·5%
Leiotriletes directus	8·0%
Leiotriletes spp.	1·0%
Osmundacidites wellmanii	0·5%
Platysaccus queenslandi	1·0%
Polyodiisporites ipsviciensis	3·0%
Punctatosporites walkomi	0·5%
Vitreisporites microsaccus	2·0%
Vitreisporites sp.	1·5%
Indeterminate	8·0%

Bore N.S. 201, 313 ft. 7 in.
Lithology.—Siltstone.
Specimens examined.—500.

Alisporites australis	3·2%
Alisporites spp.	33·2%
Araucariacites sp.	0·2%
Chordasporites sp.	0·4%
Circulina meyeriana	1·0%
cf. *Circulina* sp.	0·2%
Converrucosisporites sp.	0·2%
Cycadopites granulatus	0·2%
C. nitidus	20·0%
Dictyophyllidites mortoni	0·2%
Discisporites psilatus	0·2%
D. verrucosus	0·4%
Duplexisporites gyratus	0·2%
Foveosporites sp.	0·2%
Granulatisporites minor	1·0%
Inapertisporites minutus	0·6%
Inaperturopollenites reidi	0·2%
Leiotriletes directus	3·0%
Leiotriletes spp.	1·4%
Osmundacidites wellmanii	0·4%
Platysaccus queenslandi	0·4%
Polypodiisporites ipsviciensis	12·0%
Punctatosporites walkomi	0·2%
Stereisporites antiquasporites	0·2%
S. tenuis	0·2%
Verrucosisporites sp.	0·4%
Vitreisporites microsaccus	2·4%
Vitreisporites sp.	1·0%
Indeterminate	16·8%

Bore N.S. 221, 455 ft.
Lithology.—Siltstone.
Specimens examined.—500.

Alisporites australis	0·6%
Alisporites spp.	21·2%
Annulispora folliculosa	0·2%
A. microannulata	0·2%
Araucariacites sp.	1·2%
Chordasporites sp.	0·2%
Circulina meyeriana	1·0%
cf. *Circulina* sp.	1·8%
Converrucosisporites sp.	0·2%
Cycadopites granulatus	0·6%
C. nitidus	8·2%
Dictyophyllidites mortoni	2·0%
Discisporites psilatus	0·6%
Duplexisporites gyratus	0·2%
Foveosporites moretonensis	0·8%
Granulatisporites minor	4·2%
Inapertisporites crassus	0·2%
I. minutus	0·2%
Inaperturopollenites reidi	0·2%
Leiotriletes directus	27·0%
Leiotriletes spp.	7·8%
Osmundacidites wellmanii	2·0%
Osmundacidites sp.	0·4%
Polycingulatisporites densatus	0·2%
Polypodiisporites ipsviciensis	0·2%
Punctatisporites sp.	2·2%
Stereisporites tenuis	0·6%
Tuberculatosporites aberdarensis	0·2%
Verrucosisporites sp.	0·2%
Vitreisporites sp.	0·2%
Indeterminate	15·2%

VII. STRATIGRAPHIC CONCLUSIONS

(a) Microfloral sequence within the Bundamba Group

The vertical sequence of over 700 ft., based on samples from Bore N.S. 201, provides a starting point for study of species distribution within the Bundamba succession. This sequence may be extended to nearly 1,200 ft. by including the sample from Bore N.S. 221, 455 ft., which is, stratigraphically, the highest sample examined. Percentage distribution of selected forms, recorded in the sequence in the former drillhole, is shown graphically in Figure 2.

Some of the variations in the proportions of forms recorded appear to be related to environmental facies. This is exemplified by the relative abundance of *Stereisporites antiquasporites* and *Circulisporites parvus* (30·5 per cent. and 10·0 per cent. respectively) in the sample of coal from the Little West Moreton seam, and their rarity in the other samples. This sample differed from the others in coming from the only coal seam of appreciable thickness within the sequence. The variations in the abundance of *Alisporites* are also believed to be an effect of facies as pollens of this type extend through most of the Triassic in Australia. The genus is abundant in most samples from the Bundamba Group and its lesser abundance in a few samples, notably those from the Aberdare Conglomerate, is believed to be a reflection of facies rather than being of stratigraphic significance. Such forms are thus excluded from consideration in assessing significant vertical changes in the microflora. Excluding also species known to be long-ranged from other evidence, and others too rare to show significant variation, there remain several species which do appear to show notable changes in distribution within the sequence. They are as follows:—

(1) *Punctatosporites walkomi* and *Tuberculatosporites aberdarensis* are abundant in the Aberdare Conglomerate, the former in two and the latter in one, of the three samples studied from that formation. They are quite rare in the two overlying formations, so that their abundance in the Aberdare Conglomerate seems likely to be of stratigraphic significance.

(2) A striking new species, *Discisporites verrucosus,* reaches its acme of abundance in two samples from the Aberdare Conglomerate. It then occurs sporadically through the overlying Raceview Formation, being reduced to scant porportions in the Ripley Road Sandstone. This distribution pattern appears to be a distinctive one.

(3) The genus *Circulina* first appears near the base of the Bundamba sequence. It is relatively rare in the Aberdare Conglomerate and Raceview Formation, reaching its maximum abundance of 1 per cent. in two samples from the Ripley Road Sandstone. The significance of this distribution in comparison with the distribution of *Circulina* in the European Triassic is discussed below.

(4) Two species, *Partitisporites novimundanus* and *Duplicisporites granulatus,* appear near the base

of the Aberdare Conglomerate and die out about halfway up the sequence in the Raceview Formation. They are known in the Karnian of Europe (Klaus, 1960). The evidence thus provided on the age of the Bundamba Group is discussed in the following section.

(b) Age and Relationships of the Microflora

Previous knowledge of the age of the Bundamba Group has been based on plant macrofossils, which indicated a Triassic age (Jones and de Jersey 1947, p. 83). Ample confirmation of this age determination is now provided by the microfloral assemblages listed above. Thus pollen grains of the *Pteruchus* type (recorded as *Alisporites*) are abundant, as in the Triassic of the underlying Ipswich Coal Measures, and distinctive Ipswich species such as *Polypodiisporites ipsviciensis, Converrucosisporites cameroni* and *Punctatosporites walkomi* are also present. Furthermore, the genus *Classopollis,* which is widely distributed in the Jurassic, but is not known to range appreciably below the top of the Triassic, is absent from the assemblages. Support for regarding the range of *Classopollis* as essentially post-Triassic is provided by Klaus (Klaus 1960, p. 168) and study of the available literature suggests that the genus has not been recorded from sediments known, from independent evidence, to be definitely Triassic. Consequently, on the basis of the absence of *Classopollis,* and the distinctively Triassic aspect of the assemblages, the whole of the sequence examined, comprising the Aberdare Conglomerate, the Raceview Formation and the bottom 660 ft. of the Ripley Road Sandstone is regarded as Triassic.

The assemblages recorded also assist in attempting a more precise dating of the Bundamba succession, with the Triassic. This is based on comparison with other Triassic microfloras in Australia, and elsewhere. In Australia, microfloras from two sequences, in Western Australia and South Australia, are relevant for this purpose. They are:—(1) The Lower Triassic (Scythian) assemblage described by Balme (1963) from the Kockatea Shale of Western Australia and (2) the Rhaeto-Liassic microflora from the Leigh Creek Coal Measures studied by Playford and Dettmann (1964).

The Scythian microflora described by Balme is characterised by *Lundbladispora* and *Taeniaesporites,* both of which are absent from the Bundamba assemblages, and is lacking in *Alisporites* (of the *Pteruchus* type). Also to be considered is the presence of over 4,000 ft. of Triassic sediments, comprising the Ipswich Coal Measures (with a microflora likewise lacking Scythian affinities), underlying the Bundamba Group. There is thus strong evidence for a post-Scythian age for the Bundamba sequence.

An upper limit for the age of the Bundamba microflora is provided by comparison with that of the Leigh Creek Coal Measures. The evidence of both megaspore and microspore assemblages indicates an age close to Triassic-Jurassic boundary (i.e. Rhaeto-Liassic) for the latter sequence. On the assumption that this sequence is a conformable one, and that the appearance of *Classopollis* indicates the base of the Jurassic, the assemblage from the lowest sample studied by Playford and Dettmann (1964) would thus be regarded as Rhaetic in age. This assemblage has many forms in common with the Bundamba microflora, including distinctive species such as *Duplexisporites gyratus* and *Polycingulatisporites densatus.* However, the absence of characteristic Bundamba genera such as *Circulina, Discisporites, Duplicisporites* and *Partitisporites* from this Leigh Creek assemblage suggests an earlier (pre-Rhaetic) age for the Bundamba sequence. Consequently the net result of comparison with these two Australian microfloras is to indicate a post-Scythian, pre-Rhaetic age.

Comparison with overseas Triassic microfloras (so far known almost entirely from the Northern Hemisphere) is hampered by marked differences, reflecting environmental conditions, between the floras of Northern and Southern hemispheres during the period. In the Middle and Upper Triassic the floras of the Southern Hemisphere were dominated by *Dicroidum,* which is absent from European Triassic floras. This dominance of *Dicroidium* is reflected in the abundance of *Alisporites* (of the *Pteruchus* type) in the southern microfloras, a feature which is again lacking in the European assemblages. In the face of this dominance of the Australian Triassic microfloras by local elevents, greater importance in stratigraphic studies must be attached to the more cosmopolitan genera and species, whose wider distribution renders them more useful for purposes of correlation. Consequently the discovery, in the present investigation, of genera and species which are of restricted range in the Triassic of Europe appears quite significant. The stratigraphic evidence of such genera and species can be summarised as follows:—

(1) *Partitisporites novimundanus* and *Duplicisporites granulatus,* present in the lower part of the Bundamba sequence, are restricted to the Karnian of Austria (Klaus 1960).

(2) *Circulina meyeriana* first appears in the Karnian of Austria, becoming more abundant in the succeeding Norian (Klaus 1960, p. 165). The species is absent from the Ipswich Coal Measures, rare in the Aberdare Conglomerate and Raceview Formation, becoming more abundant in the Ripley Road Sandstone.

(3) *Circulina* sp. 1, present in the Raceview Formation, is restricted to the Karnian of Austria (Personal communication from Dr. Klaus dated February 12th, 1964).

Comparison with the Austrian sequence, which is regarded as a standard section for the Triassic, thus favours a Karnian age for the lower part of the Bundamba sequence. An early Norian age may be suggested for the upper part (the Ripley Road Sandstone) in which *Partitisporites* and *Duplicisporites* are absent and *Circulina meyeriana* becomes slightly more abundant. This Karnian to Norian age indicated for the Bundamba assemblages is in agreement with

evidence from comparison with Australian Triassic microfloras, as it falls within the post-Scythian, pre-Rhaetic interval suggested above. From the aspect of palaeogeography, the evidence suggests that conditions permitting limited migration of certain plant species between Gondwanaland and the European area existed in Upper Triassic times.

Microfloral studies have also provided fresh evidence on the age of the underlying Ipswich Coal Measures, a Group regarded as Middle Triassic on macro-floral evidence (Jones and de Jersey, 1947). The Ipswich and Bundamba assemblages have much in common (suggesting that the intervening disconformity represents a relatively short time interval), but there are certain species restricted to each. Thus *Tenuisaccites fragilis* and *Cingulatisporites pallidus* are present in the Ipswich, but not in the Bundamba micro-flora, while species present in the Bundamba, but missing from the Ipswich sequence include:—*Circulina meyeriana, Foveosporites moretonensis, Discisporites verrucosus, Partitisporites novimundanus, Tuberculatosporites aberdarensis, Lycopodiumsporites antiquus* and *Vitreisporites microsaccus.*

The Karnian element is less prominent in the Ipswich assemblages, *Circulina* and *Partitisporites* both being absent, although *Duplicisporites granulatus* and *Discisporites psilatus* have recently been observed in samples from the Brisbane area. These samples came from horizons correlated with the lower part of the Group (Tivoli Formation or Kholo Sub-Group) in the type area. Also, in some of these samples, a small proportion of striate bisaccate pollens (assigned to the genera *Striatites* and *Taeniaesporites*) has been observed. Pollen grains of this type are common in Lower Triassic sediments in Australia, but have not been observed in the upper part of the Ipswich sequence or in the Bundamba Group. All these features, together with the disconformity between the Bundamba and Ipswich sequences, suggest a possible extension of the latter downwards from the Karnian into the preceding Ladinian. A more precise determination of the age of the basal part of the Ipswich succession cannot be attempted until accounts of accurately dated microfloras, of Ladinian and Anisian age, have been published to provide a basis for comparison. The above suggestions regarding the ages of the Bundamba and Ipswich sequences, based on microfloral evidence, are indicated below (Table 3).

TABLE 3

AGE OF BUNDAMBA GROUP AND IPSWICH COAL MEASURES

UPPER TRIASSIC	RHAETIC	
	NORIAN	BUNDAMBA GROUP
	KARNIAN	IPSWICH COAL MEASURES
MIDDLE TRIASSIC	LADINIAN	——?——?——?——
	ANISIAN	
LOWER TRIASSIC	SCYTHIAN	

(c) Stratigraphic Applications

The terms "Bundamba Sandstone" or "Bundamba Group" have, in the past, been frequently applied to sediments in Queensland considered, on lithological evidence, to be equivalent to the Bundamba Group of the type area. Microfloral evidence has now accumulated which enables the time relationships of the sediments involved to be assessed more precisely. The principal example of the use of the term "Bundamba" away from the type area is in the Great Artesian Basin, where formations underlying equivalents of the Walloon Coal Measures have been assigned to the Bundamba Group. The history of the use of the term is discussed by Tweedale (1960, p. 283). The sediments concerned are grouped into the following units, in ascending stratigraphic order:—Precipice Sandstone, Evergreen Shale, Boxvale Sandstone and Hutton Sandstone.

Recent palynologic studies (de Jersey and Paten 1963a) have shown that these units contain Jurassic microfloras. Consequently, as the Triassic character of the Bundamba microflora has now been demonstrated, the formations concerned cannot have time equivalents in the Bundamba Group of the type area. In addition there is no convincing evidence for lithological continuity of the Bundamba Group from the type area into the Artesian Basin. Accordingly it is considered that use of the term "Bundamba Group" in the Artesian Basin should be discontinued.

More recently, McTaggart (1963, Table 1) has correlated the Bundamba Group of the type area with the lower part of the sequence in the Artesian Basin, namely the Precipice Sandstone and portion of the Evergreen Shale. As indicated above, this correlation is not supported by microfloral evidence. The microflora of the Precipice Sandstone has a persistently Jurassic character over a large area in the Surat sub-basin; for the unit to be even a lithological extension of the Bundamba Group would necessitate an abrupt diachronism in passing from the Surat sub-basin to the Moreton basin, which seems most unlikely.

The investigation has also provided evidence on the time relationship between the Bundamba Group and the Marburg Sandstone. Denmead (1955, p. 6) considered that these two sequences were separated by an unconformity. Subsequently, however, Freytag (1963, pp. 233-237) described a gradational transition from "Bundamba-type" sandstone to "Marburg-type" sandstone in the Ripley Road-Deebing Creek area. Microfloral evidence, indicating a Triassic age for the Bundamba Group (see above) and a Jurassic age for the Marburg Sandstone (de Jersey, 1963) supports the conclusions of the former author. The Marburg Sandstone of the type area can be correlated with the Hutton Sandstone of the Surat sub-basin (de Jersey and Paten 1963b). If it were to succeed directly the

Triassic sediments of the Bundamba Group there would necessarily be an hiatus or non-sequence involving at least the absence of equivalents of the Evergreen Shale and Precipice Sandstone (which underlie the Hutton Sandstone in the Surat sub-basin). A sequence including such a time break could not be regarded as a conformable one and consequently any contact discovered between the units (the Marburg Sandstone and Bundamba Group) seems likely to be an unconformity or at least a disconformity. It also seems probable that it will prove difficult to distinguish sediments of the Marburg Sandstone from the Bundamba Group, on purely lithological evidence, and that "Marburg-type" sandstones may occur in the Bundamba Group, and *vice versa.*

In another area, the Landsborough Sandstone of the Moreton district was previously correlated with the Bundamba Group of the type area (Dunstan 1915, p. 3; David 1932, Table F). Sediments assigned to the Landsborough Sandstone in the Toorbul Point area have been shown to be time equivalents of the Evergreen Shale (de Jersey and Paten, 1963c). Thus the Landsborough Sandstone, in this area at least, can no longer be regarded as a time equivalent of the Bundamba Group.

The conclusion is thus evident that time equivalents of the Bundamba Group of the type area have not yet been found elsewhere in Queensland. Sediments previously correlated with the Group, on lithological evidence, have been shown to be equivalent to other, mainly younger, formations wherever adequate microfloral evidence is available.

VIII. ACKNOWLEDGMENTS

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EXPLANATION OF PLATES

PLATE 1

(All photographs approximately X1000)

Figure 1.—*Stereisporites antiquasporites* (Wilson and Webster) Dettmann.
Figure 2.—*Stereisporites antiquasporites* (Wilson and Webster) Dettmann.
Figure 3.—*Stereisporites antiquasporites* (Wilson and Webster) Dettmann.
Figure 4.—*Annulispora microannulata* de Jersey.
Figure 5.—*Lycopodiumsporites antiquus,* n.sp. (Holotype).
Figure 6.—*Osmundacidites* sp.
Figure 7.—*Foveosporites moretonensis,* n. sp. (Holotype).
Figure 8.—*Foveosporites moretonensis,* n. sp.
Figure 9.—*Foveosporites* sp.
Figure 10.—*Polycingulatisporites densatus* (de Jersey) Playford and Dettmann.
Figure 11.—*Polycingulatisporites densatus* (de Jersey) Playford and Dettmann.
Figure 12.—cf. *Circulina* sp.
Figure 13.—*Duplexisporites gyratus* Playford and Dettmann.
Figure 14.—*Duplexisporites gyratus* Playford and Dettmann.
Figure 15.—*Duplexisporites gyratus* Playford and Dettmann.
Figure 16.—*Polypodiisporites ipsviciensis* (de Jersey) Playford and Dettmann.
Figure 17.—*Tuberculatosporites aberdarensis,* n. sp. (Holotype).
Figure 18.—*Tuberculatosporites aberdarensis,* n. sp. (Paratype).

PLATE 2

(All photographs approximately X1000)

Figure 1.—*Alisporites australis* de Jersey.
Figure 2.—*Platysaccus queenslandi* de Jersey.
Figure 3.—*Vitreisporites microsaccus,* n. sp.
Figure 4.—*Vitreisporites microsaccus,* n. sp.
Figure 5.—*Vitreisporites microsaccus,* n. sp. (Holotype)
Figure 6.—*Partitisporites novimundanus* Leschik.
Figure 7.—*Partitisporites novimundanus* Leschik.
Figure 8.—cf. *Duplicisporites* sp.
Figure 9.—*Discisporites psilatus,* n. sp. (Holotype).
Figure 10.—*Circulina meyeriana,* Klaus.
Figure 11.—*Discisporites psilatus,* n. sp.
Figure 12.—*Duplicisporites* sp.
Figure 13.—*Discisporites verrucosus,* n. sp.
Figure 14.—*Circulina* sp. 1.
Figure 15.—*Discisporites verrucosus,* n. sp. (Holotype).
Figure 16.—*Discisporites verrucosus,* n. sp.
Figure 17.—*Circulina* sp. 1.

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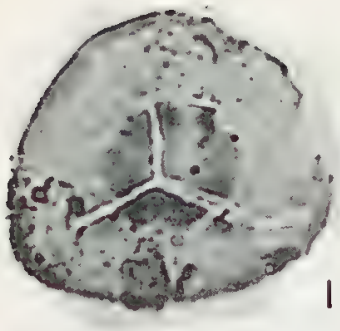
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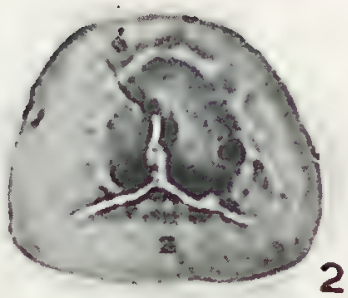
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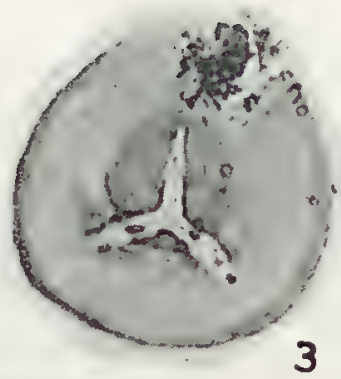
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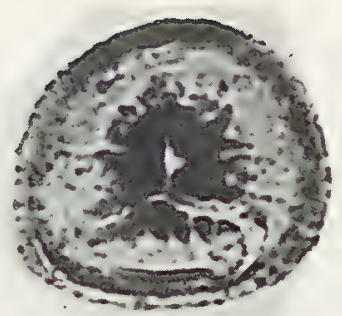
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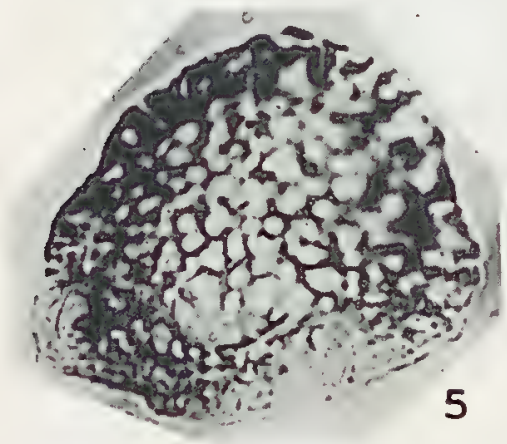
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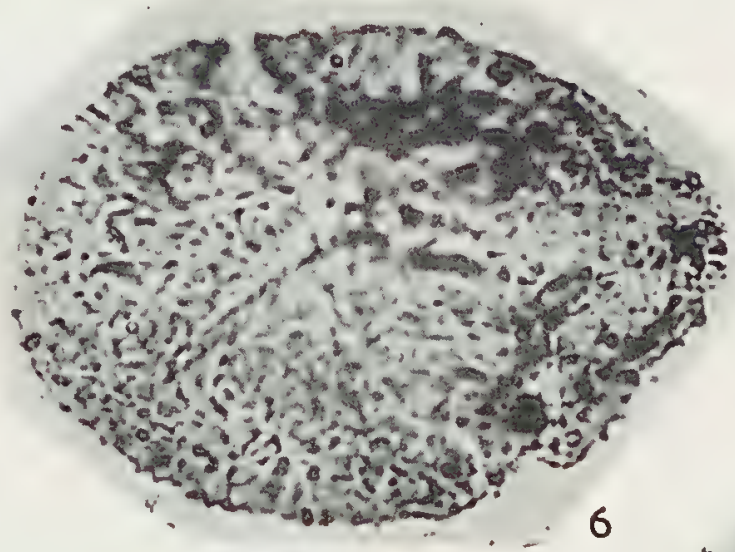
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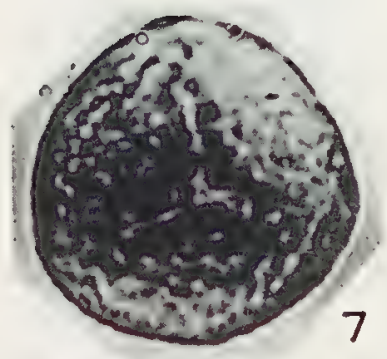
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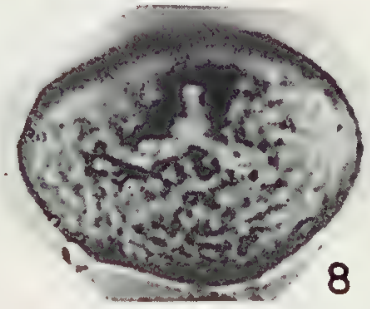
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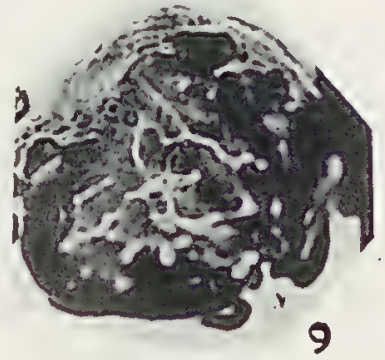
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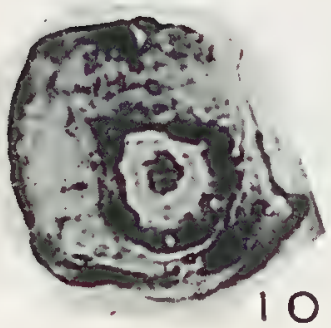
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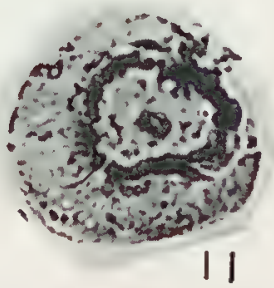
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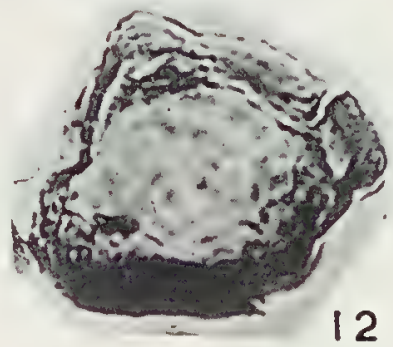
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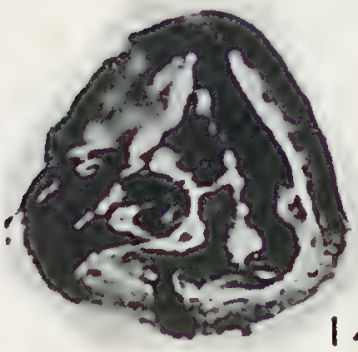
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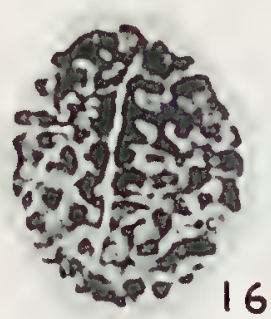
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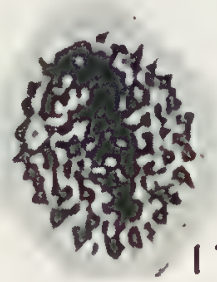
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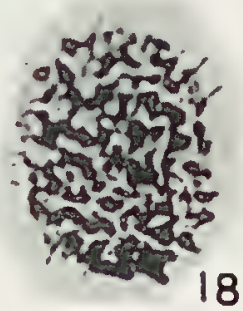
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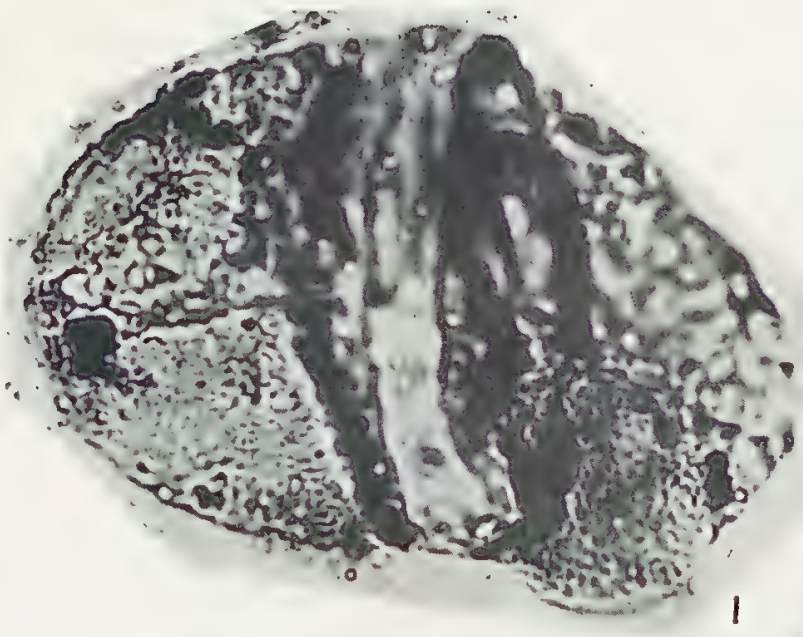
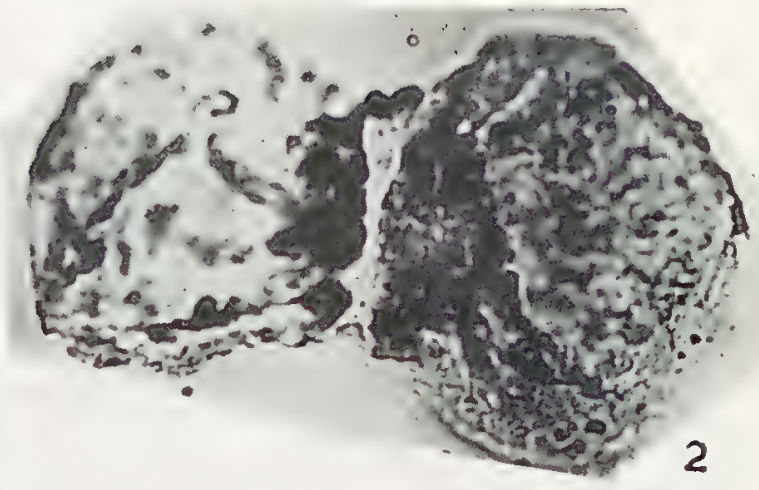
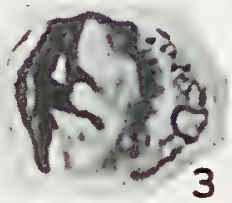
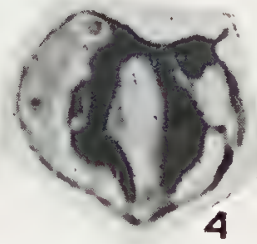
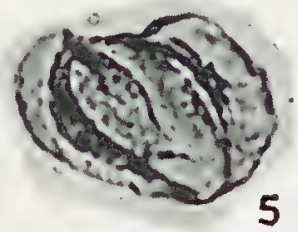
PLATE 1

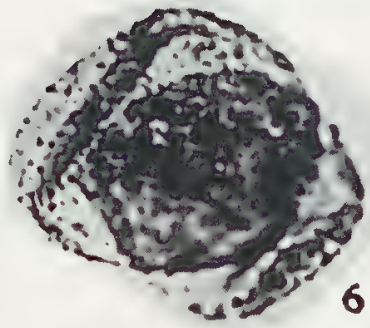


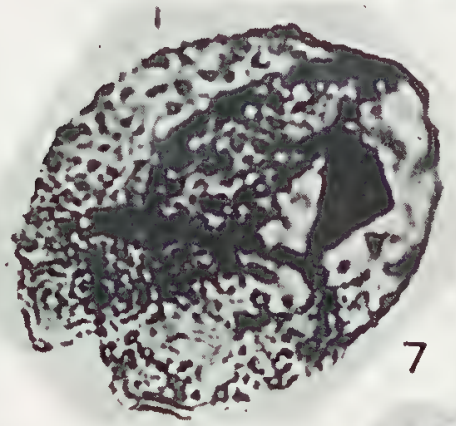


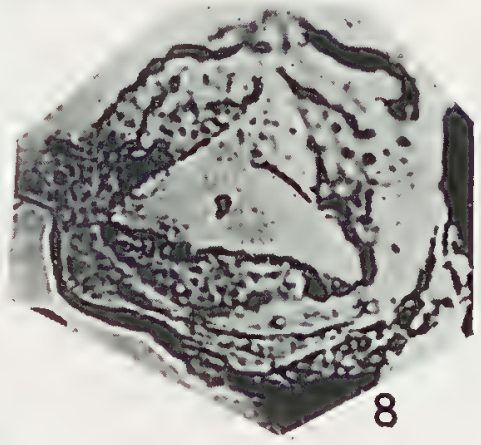


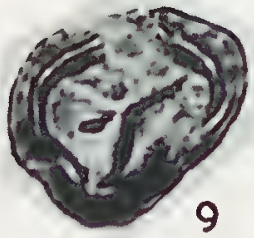


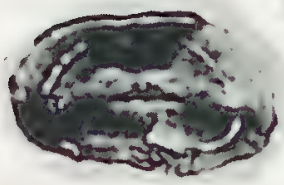


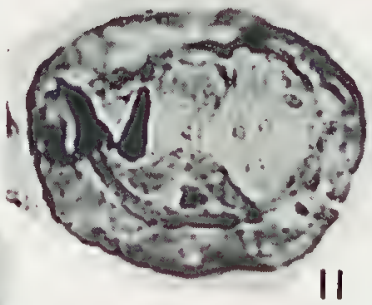


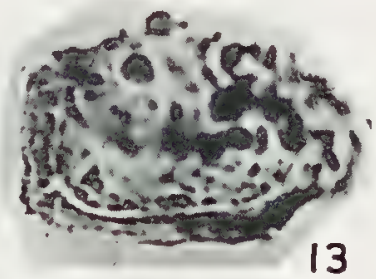


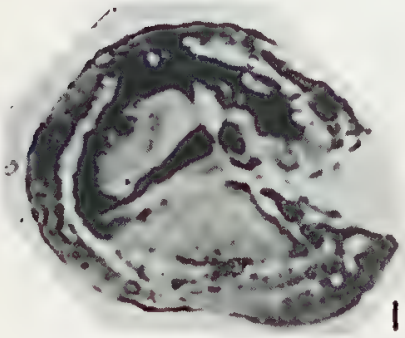


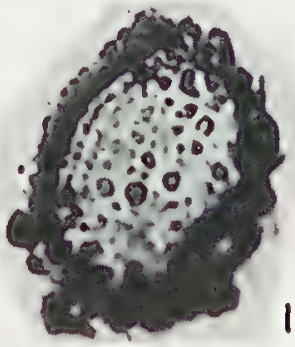


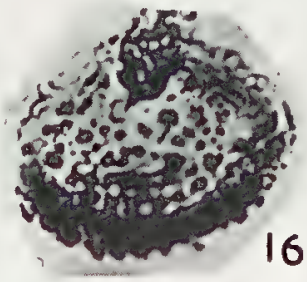












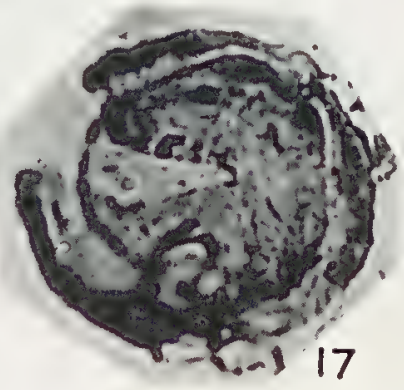
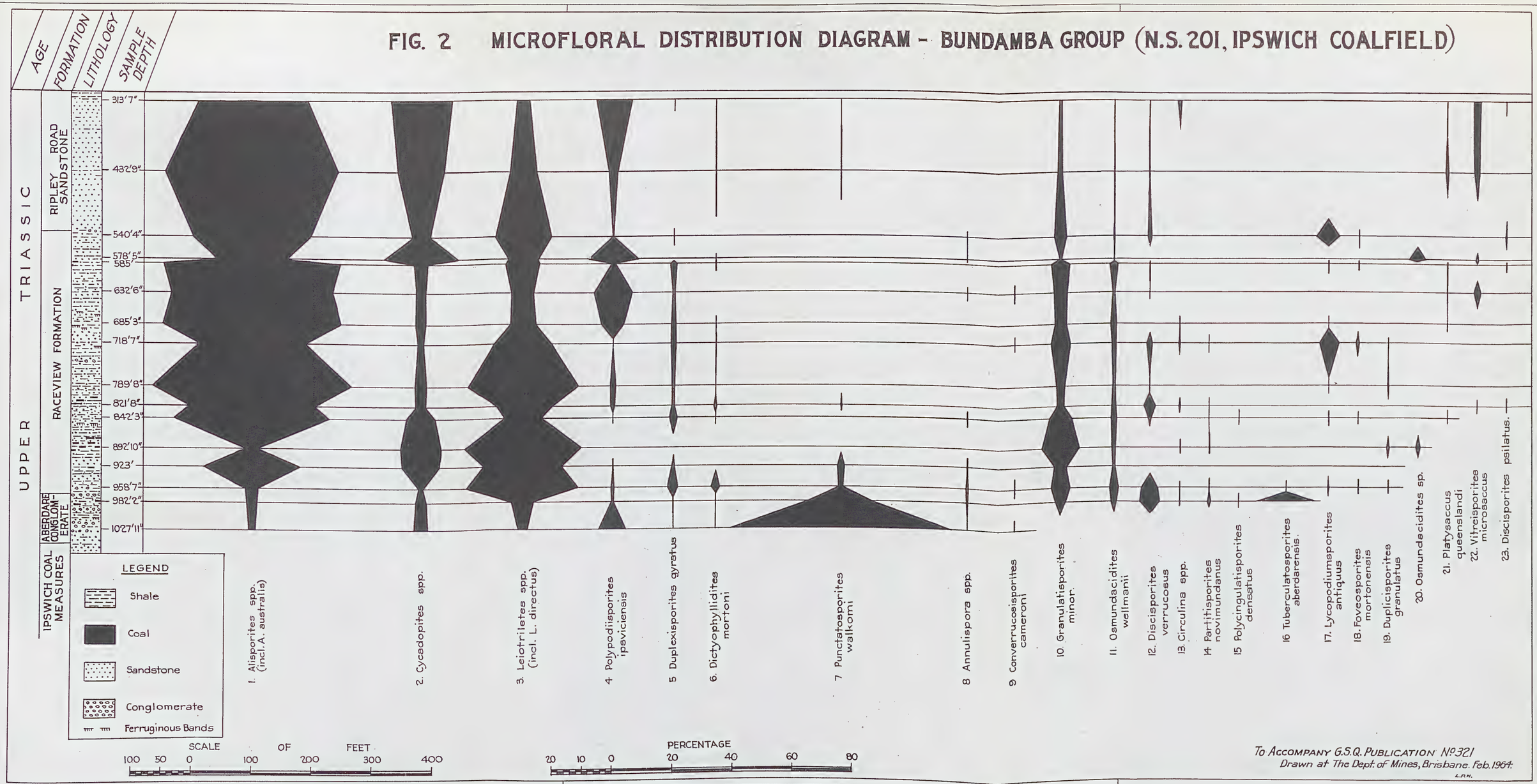


PLATE 2

FIG. 2 MICROFLORAL DISTRIBUTION DIAGRAM - BUNDAMBA GROUP (N.S. 201, IPSWICH COALFIELD)



To Accompany G.S.Q. Publication No. 321
Drawn at The Dept. of Mines, Brisbane. Feb. 1964.
L.P.H.

QUEENSLAND
DEPARTMENT OF MINES

...OF VICTORIA

GEOLOGICAL SURVEY OF QUEENSLAND

(A. K. Denmead, M.Sc., Chief Government Geologist)

PUBLICATION No. 322

JURASSIC SPORES AND POLLEN GRAINS FROM THE SURAT BASIN

By N. J. de JERSEY, Ph.D., M.Sc., Supervising Geologist
and R. J. PATEN, B.Sc., Geologist

BRISBANE
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PREFACE

This paper by Dr. de Jersey and Mr. Paten is the fifth in a series recording descriptions of spore and pollen species from the major sedimentary formations of Queensland. In some respects it is more comprehensive than previous papers in this series, dealing as it does with samples from a larger area and from three different formations. Palynology is proving extremely useful in correlation studies in these Jurassic sediments, which contain the major oil and gas reservoir sands of the Artesian Basin. Currently the Geological Survey is engaged in a study of samples from wells drilled by the Union Oil Development Corporation and the Phillips Petroleum Company, samples from the area explored by Associated Australian Oilfields being studied by the Bureau of Mineral Resources. Consequently the present investigation is based largely on material from the former Companies. The applications of palynology to petroleum prospecting include (*a*) age determinations, based on selected samples and (*b*) correlation studies, based on stratigraphic ranges and distribution of key species. Evidence on the age of the sediments is summarised in the present paper, while correlation studies will be materially assisted by the descriptions and photographs of the species recorded. These applications amply justify the provision by the Department of this specialised service to petroleum prospecting in Queensland.

A. K. DENMEAD,
Chief Government Geologist.

149°
150°
151°
25°
26°
27°
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29°
PRE—JURASSIC
BASEMENT
Q.M.D.
C.R.5
EIDSVOLD
TAROOM
INJUNE
ROMA
MILES
SURAT
BASIN
SURAT
DALBY
TARA
CECIL PLAINS
P.S.
Cecil Plains 1
P.S.Q. Durabilla West 1
P.S.Q. Waggaba 1
P.S.Q. Tinker Ck. 1
U.K.A. Moonie 3
U.K.A. Iminbah 1
U.K.A. Yarrill Ck. 1
P.S. Charleys Ck.
Scouts
4.
7.
20.
19
GOONDIWINDI
NEW SOUTH WALES
PRE—JURASSIC BASEMENT

FIG. 1
LOCALITY PLAN
SURAT BASIN

SCALE OF MILES
32 16 0 32

Drawn at the Dept. of Mines, Queensland June 1964
J.E.C.

JURASSIC SPORES AND POLLEN GRAINS FROM THE SURAT BASIN

by

N. J. DE JERSEY, Ph.D.; M.Sc., Supervising Geologist, and
R. J. PATEN, B.Sc., Geologist

ABSTRACT

Thirty-seven species of spores and pollen are recorded from the Surat Basin, in southern Queensland. The specimens described came from the lower part of the Jurassic sequence in the basin, the formations represented being the Precipice Sandstone, Evergreen Shale and Hutton Sandstone. From the taxonomic aspect, six new species are proposed; three of these are placed in a new genus, *Cadargasporites,* while the other new genus proposed, *Nevesisporites,* is monotypic. Emendation of the generic diagnosis of *Classopollis* (Pflug) Pocock and Jansonius is proposed as a result of study of the Queensland material. From the stratigraphic aspect, the age of the microfloras is discussed, on the basis of comparison with the Jurassic microfloral sequence in Western Australia.

1. INTRODUCTION

The discovery and development of the Moonie oilfield, in southern Queensland, has been accompanied by the drilling of numerous wells in the Surat Basin. This basin, a sub-basin of the Great Artesian Basin, contains a succession of Mesozoic sediments, the reservoir sands at Moonie being near the base of the Jurassic portion of the sequence. Core samples of the Jurassic sediments from many of these wells have been submitted to the Geological Survey by the companies concerned, and correlation studies are currently in progress. The purpose of this paper is to record descriptions of species present in cores from the lower part of this Jurassic sequence, particular attention being directed to those of importance in current correlation studies. Among these species are some new forms which appear to be restricted in range to portions of the sequence; description of them is a necessary prerequisite to their use in establishing formal biostratigraphic units. The present investigation should be regarded as an initial step in elucidating the morphology and taxonomy of the microflora, as it is likely that further study of the abundant material available will lead to the discovery of additional new species and also advance knowledge of the described forms.

2. STRATIGRAPHIC SUMMARY

A representative section of the Jurassic sediments of the Surat Basin is provided by the sequence penetrated in the Moonie oilfield. On the basis of data provided by the Union Oil Development Corporation, this sequence can be summarised as follows (in descending stratigraphic order):—

Stratigraphic Unit	Approximate Thickness (feet)
Blythesdale Group (Sandstone, shale, coal)	2,100
Walloon Formation (Interbedded shale and coal)	1,000
Hutton Sandstone (Dominantly sandstone, minor siltstone and shale)	600
Evergreen Shale (Dominantly shale, minor sandstone and siltstone)	550
Precipice Sandstone (Dominantly sandstone, minor siltstone and shale)	250

The Boxvale Sandstone, a unit known from below the Hutton Sandstone in outcrop north of Roma, is not included in this list as it has not been definitely recognised by the Union and Phillips geologists in the subsurface sections, from which samples have been obtained. With the exception of the Blythesdale Group, the upper part of which may extend into the basal Cretaceous, all the above units are regarded as entirely Jurassic in age.

The samples examined have come mainly from wells drilled by the Union Oil Development Corporation and Phillips Petroleum Company (see Locality map—Figure 1). They represent horizons in the Precipice Sandstone, Evergreen Shale and Hutton Sandstone, with the two former formations predominating. For each species, in the following text, the formations from which it has been recorded are listed. Precise determination of the stratigraphic ranges of many of the species must await completion of correlation studies currently in progress.

3. EXPERIMENTAL METHOD

The technique used for maceration of shales and siltstones was similar to that previously described (de Jersey 1963, pp. 1, 2). The samples were first treated

with dilute hydrochloric acid to remove calcium-carbonate, if necessary. Silicates were then decomposed by heating in hydrofluoric acid at its constant boiling point concentration, aluminium fluoride formed in the process being removed by treatment with dilute hydrochloric acid. The carbonaceous matter liberated was treated with Schulze solution (potassium chlorate and concentrated nitric acid) for periods up to two hours, and then finally washed with dilute sodium hydroxide solution. The residue was washed to neutrality at each stage of the process, using a centrifuge for this purpose. Coals were macerated by a modified version of this technique, treatment with hydrofluoric acid being omitted.

The final maceration residue was mounted on microslides, using Canada balsam–xyol solution as the mounting medium. Specimens selected for photographing were located with a Carl Zeiss (Oberkochen) microscope by means of their stage co-ordinates expressed to the nearest 0·1 mm. In addition the co-ordinates of an easily located reference point, selected as the lower right-hand corner of the cover glass of each slide, have been determined in each case. This reference point is quoted in the text, along with the co-ordinates of each holotype or figured specimen, so that with this information the specimens can be readily located by means of any microscope equipped with a mechanical stage. All microslides are stored in the palynological collection of the Geological Survey of Queensland.

Photographs were taken using a Leitz "Makam" camera attachment and an oil immersion (X100) objective. Negatives were made directly on "Kodalith" Panchromatic plates from which contact prints were produced on Velox paper. The approximate magnification is X1000 in all cases.

4. SYSTEMATIC DESCRIPTIONS

? Division BRYOPHYTA

Genus STEREISPORITES (Pflug) de Jersey

Stereisporites antiquasporites (Wilson and Webster) Dettmann

Plate 1, Figures 1 and 2

Figured specimen (Distal view—Plate 1, Figure 1).—Slide S. 43, stage co-ordinates 38·9, 97·4; diameter 26 microns. Co-ordinates of lower right-hand corner of cover glass 46·1, 86·6.

Locality.—P.S. Charleys Creek Scout Bore No. 4, 120 ft. to 130 ft.

Figured specimen (Proximal view—Plate 1, Figure 2).—Slide O.D. 2062, stage co-ordinates 40·0, 84·5; diameter 21 microns. Co-ordinates of lower right-hand corner of cover glass 57·8, 82·4.

Locality.—P.S.Q. Waggaba No. 1 well, sidewall core No. 16 (3,340 ft.).

Remarks.—This species has previously been recorded from the Upper Triassic of the Bundamba Group, the morphology and taxonomy being discussed on the basis of specimens from the Bundamba sequence (de Jersey 1964). The specimens from the Surat Basin show some variation in the thickness and size of the distal thickening, but in view of the continuous nature of this variation, the species is interpreted broadly to include them.

Distribution.—Precipice Sandstone and Lower Evergreen Shale (Surat Basin); Rhaeto-Liassic of Leigh Creek Coal Measures (Playford and Dettmann 1964); Cretaceous of south-eastern Australia (Dettmann 1963); Jurassic and Lower Cretaceous of Western Australia (Balme 1957); Upper Triassic of Bundamba Group (de Jersey 1964); Tertiary of Montana (Wilson and Webster 1946); Cretaceous of Western Canada (Pocock 1962).

Division LYCOPODOPHYTA

Genus LYCOPODIUMSPORITES Thiergart ex Delcourt and Sprumont

Lycopodiumsporites austroclavatidites (Cookson) Potonié

Plate 1, Figures 6 and 7

Figured specimen (Proximal and distal foci—Plate 1, Figures 6, 7).—Slide O.D. 2116, stage co-ordinates 35·0, 95·0; diameter 41 microns. Co-ordinates of lower right-hand corner of cover glass 46·8, 84·4.

Locality.—P.S.Q. Waggaba No. 1 well, sidewall core No. 9 (3,688 ft.).

Distribution.—Precipice Sandstone, Evergreen Shale, Hutton Sandstone, Blythesdale Group (Surat Basin); Cretaceous of South-Eastern Australia (Dettmann 1963); Jurassic and Lower Cretaceous of Western Australia (Balme 1957); Rhaeto-Liassic of Leigh Creek Coal Measures (Playford and Dettmann 1964).

Lycopodiumsporites rosewoodensis de Jersey

Plate 1, Figure 5

Figured specimen (Plate 1, Figure 5).—Slide S. 42, stage co-ordinates 43·0, 98·2; diameter 30 microns. Co-ordinates of lower right-hand corner of cover glass 45·3, 88·9.

Locality.—P.S. Charleys Creek Scout Bore No. 4, 120 ft. to 130 ft.

Distribution.—Precipice Sandstone, Evergreen Shale, Hutton Sandstone, Walloon Formation, Blythesdale Group (Surat Basin); Walloon Coal Measures of Rosewood Coalfield (de Jersey 1959); Marburg Sandstone (de Jersey 1963).

Division PTEROPHYTA

Genus OSMUNDACIDITES Couper

Osmundacidites wellmanii Couper

Distribution.—Precipice Sandstone, Evergreen Shale, Hutton Sandstone, Walloon Formation, Blythesdale Group (Surat Basin); Upper Mesozoic of S.E. Australia (Dettmann 1963); Upper Triassic of Bundamba Group (de Jersey 1964); Cretaceous of Western

Canada (Pocock 1962); Rhaeto-Liassic of Leigh Creek Coal Measures (Playford and Dettmann 1964); Jurassic of Marburg Sandstone (de Jersey 1963).

SPORES—INCERTAE SEDIS

Genus BACULATISPORITES Thomson and Pflug

Baculatisporites comaumensis (Cookson) Potonié

Plate 1, Figures 8 and 9

Figured specimen (Proximal and distal foci—Plate 1, Figures 8, 9).—Slide O.D. 2114, stage co-ordinates 37·4, 96·6; diameter 44 microns. Co-ordinates of lower right-hand corner of cover glass 48·3, 81·8.

Locality.—P.S.Q. Waggaba No. 1 well, sidewall core No. 9 (3,688 ft.).

Remarks.—Pocock (1962, p. 35) regarded this species as a synonym of *Osmundacidites wellmanii* Couper. However, the two species were considered to be distinct by Dettmann (1963, p. 34). Study of specimens from the Surat Basin supports the conclusions of the latter author. Continuous gradation in ornament, which would be expected if the species were synonymous, has not been observed in the Queensland material.

Distribution.—Precipice Sandstone, Evergreen Shale, Roma Formation (Surat Basin); Upper Mesozoic of South-eastern Australia (Dettmann 1963); Jurassic-Lower Cretaceous of Western Australia (Balme 1957); Upper Triassic of Europe (Klaus 1960).

Genus ANNULISPORA de Jersey

Annulispora folliculosa (Rogalska) de Jersey

Plate 1, Figure 4

Figured specimen (Plate 1, Figure 4).—Slide O.D. 2156; stage co-ordinates 38·7, 94·0; diameter 28 microns. Co-ordinates of lower right-hand corner of cover glass 47·1, 82·8.

Locality.—Phillips–Sunray Cecil Plains No. 1 well, sidewall core No. 7 (3,317 ft.).

Distribution.—Precipice Sandstone, Evergreen Shale, Hutton Sandstone, Walloon Formation, Blythesdale Group (Surat Basin); Walloon Coal Measures of Rosewood coalfield (de Jersey 1959); Triassic of Ipswich Coal Measures (de Jersey 1962); Jurassic of Marburg Sandstone (de Jersey 1963); Upper Triassic of Bundamba Group (de Jersey 1964); Liassic of Poland (Rogalska 1954).

Annulispora microannulata de Jersey

Plate 1, Figure 3

Figured specimen (Plate 1, Figure 3).—Slide O.D. 1969; stage co-ordinates 38·3, 102·9; diameter 26 microns. Co-ordinates of lower right-hand corner of cover glass 47·3, 87·2.

Locality.—Phillips–Sunray Cecil Plains No. 1 well, Core 3 (3,636 ft.).

Distribution.—Precipice Sandstone, Evergreen Shale, Walloon Formation (Surat Basin); Triassic of Ipswich Coal Measures (de Jersey 1962); Upper Triassic of Bundamba Group (de Jersey 1964); Jurassic of Marburg Sandstone (de Jersey 1963).

Genus MATONISPORITES (Couper) Dettmann

Matonisporites sp.

Plate 1, Figures 11 and 12

Description.—Amb triangular with rounded apices and straight to concave sides. Equatorial diameter (based on 5 measured specimens) 48 to 59 microns. Trilete; straight laesurae, extending almost to equator, with elevated lips (1 to 2 microns high) and weakly thickened margins. Exine one-layered, about 2 microns thick in inter-radial regions; thicker (5 to 8 microns) in each equatorial, radial region. Proximal exine with small punctae (about 1 micron), about 1 micron apart, uniformly distributed over entire proximal face or restricted to portion adjacent to laesurae. Distal exine smooth.

Figured specimen (Plate 1, Figure 11).—Slide O.D. 2042, stage co-ordinates 40·1, 89·2; diameter 48 microns. Co-ordinates of lower right-hand corner of cover glass 46·4, 85·9.

Locality.—P.S.Q. Waggaba No. 1 well, sidewall core No. 18 (3,220 ft.).

Figured specimen (Plate 1, Figure 12).—Slide O.D. 2040, stage co-ordinates 37·8, 89·0; diameter 58 microns. Co-ordinates of lower right-hand corner of cover glass 48·6, 84·9.

Locality.—P.S.Q. Waggaba No. 1 well, sidewall core No. 18 (3,220 ft.).

Remarks.—This species resembles *M. cooksoni* (Dettmann 1963, p. 59) and differs from other described species of the genus in having proximal punctae. It differs from that species in being slightly smaller, in having straight, not sinuous laesurae, and in the tendency of the valvae to become lobate. The latter feature also distinguishes it from other described species of the genus. This slight "dimpling" of the valvae is, however, not regarded as a sufficiently prominent sculptural feature to warrant exclusion of the species from *Matonisporites*.

The specimens recorded are distinctive, and on the available evidence, different from previously described species of the genus. Accordingly, although insufficient specimens have been found to warrant proposal of a new specific name, they are recorded and figured for future reference.

Distribution.—Upper Evergreen Shale, basal Hutton Sandstone (Surat Basin).

Genus TRIPARTINA Maljavikina ex Potonié

Tripartina cf. *T. variabilis* Maljavikina

Plate 1, Figure 10

Description (based on Queensland specimens).—Amb triangular with straight or slightly concave sides and rounded to bluntly pointed angles. Equatorial

diameter (based on 3 measured specimens) 26 to 30 microns. Trilete, well defined laesurae, slightly to distinctly sinuous, with slightly thickened lips (about 1 micron) extending to periphery. Proximal exine smooth, distal exine with shallow channels about 1 micron in width, with irregular radial arrangement, separated by smooth intervening areas of variable width (average 2–3 microns). Exine about 1 micron in thickness.

Figured specimen (Plate 1, Figure 10).—Slide O.D. 2138; stage co-ordinates 35·9, 93·3; diameter 28 microns. Co-ordinates of lower right-hand corner of cover glass 46·4, 87·7.

Locality.—Phillips–Sunray Cecil Plains No. 1 well, sidewall core No. 9 (2,851 ft.).

Remarks.—On the basis of Potonié's description and line drawing (1960, p. 48) specimens from the Surat Basin are compared with this species, Maljavikina's original description not being available at the time of writing. The Queensland specimens appear to be even more closely comparable with *T. variabilis* than those recorded from the Cretaceous by Dettmann (1963, p. 41) as *Tripartina* cf. *T. variabilis*. They are also closer in age to Maljavikina's specimens, which came from the Middle Jurassic of Emba, U.S.S.R.

Distribution.—Evergreen Shale (Surat Basin).

Genus FORAMINISPORIS Krutzsch

Foraminisporis tribulosus Playford and Dettmann

Plate 2, Figures 1 and 2

Figured specimen (Proximal focus, Plate 2, Figure 1).—Slide O.D. 2242, stage co-ordinates 41·3, 88·4; diameter 35 microns. Co-ordinates of lower right-hand corner of cover glass 47·6, 84·0.

Locality.—Union–Kern–A.O.G. Iminbah No. 1 well, sidewall core No. 2 (5,659 ft.).

Figured specimen (Distal focus, Plate 2, Figure 2).—Slide O.D. 2241, stage co-ordinates 37·5, 97·2; diameter 40 microns. Co-ordinates of lower right-hand corner of cover glass 48·3, 86·8.

Locality.—Union–Kern–A.O.G. Iminbah No. 1 well, sidewall core No. 2 (5,659 ft.).

Remarks.—Specimens from the Surat Basin have all the diagnostic features of this species, described from the Leigh Creek Coal Measures (Playford and Dettmann 1964). The specimen figured in distal focus (Plate 2, Figure 2) shows similar distal sculpture to those illustrated by Playford and Dettmann (1964, pl. 3, figs. 2, 3) while that figured in proximal focus (Plate 2, Figure 1) shows the three characteristic proximal verrucae (cf. Playford and Dettmann 1964, pl. 3, fig. 1). According to Dr. Playford (Verbal communication) these verrucae are difficult to detect in poorly preserved (? abraded) specimens and this is in accordance with observations of specimens from the Surat Basin.

Distribution.—In the Surat Basin known from one locality near the base of the Precipice Sandstone (Union–Kern–A.O.G. Iminbah No. 1 well, sidewall core No. 2 (5,659 ft.)); Rhaeto-Liassic of Leigh Creek Coal Measures (Playford and Dettman 1964).

Genus FOVEOTRILETES van der Hammen ex Potonié

Foveotriletes parviretis (Balme) Dettmann

Plate 2, Figure 3

Figured specimen (Plate 2, Figure 3).—Slide O.D. 2259, stage co-ordinates 40·5, 88·0; diameter 48 microns. Co-ordinates of lower right-hand corner of cover glass 46·4, 83·2.

Locality.—P.S.Q. Zig Zag No. 1 well, sidewall core No. 8 (1,851 ft.).

Remarks.—Specimens from the Surat Basin agree, in all essential diagnostic characters, with the species, originally described by Balme (1957, pp. 24, 25) as *Microreticulatisporites parviretis* and subsequently transferred as a new combination to *Foveotriletes* by Dettmann (1963, p. 42). The principal variation in specimens of the species is in the distinctness and extent of the reticulate ornament.

Distribution.—Hutton Sandstone, Blythesdale Group (Surat Basin); Lower Cretaceous of Western Australia (Balme 1957); Upper Mesozoic of south-eastern Australia (Dettmann 1963).

Genus ISCHYOSPORITES Balme

Ischyosporites marburgenis de Jersey, Emend.

Plate 2, Figure 4

Emended diagnosis.—Amb triangular to sub-triangular, sides straight, slightly concave or convex, apices rounded. Trilete, distinct straight laesurae extending to, or almost to, the periphery, usually bordered by weakly thickened margins. Diameter (based on 38 measured specimens) 40 to 70 microns. Exine 2 to 4 microns, except for apical (radial equatorial) regions, where the thickness is 5 to 7 microns. Distal and equatorial region with ridges anastomosing to form a fairly regular reticulum (foveo-reticulate sculpture) with oval to sub-circular lumina 2 to 6 (mostly 3 to 4) microns in diameter separated by muri about 3 microns in width. Lumina shallower in distal polar region. Proximal exine smooth, scabrate or finely granulate.

Figured specimen (Plate 2, Figure 4).—Slide O.D. 2140, stage co-ordinates 30·5, 93·9; dimensions 49 × 54 microns. Co-ordinates of lower right-hand corner of cover glass 48·2, 85·8.

Locality.—Phillips–Sunray Cecil Plains No. 1 well, sidewall core No. 9 (2,851 ft.).

Remarks.—The specific diagnosis (de Jersey 1963, pp. 5, 6) is here emended on the basis of additional information obtained from study of specimens from the Surat Basin and also from the work of Playford and Dettmann (1964), who have recorded the species from the Leigh Creek Coal Measures. The principal alteration is in allowing for the presence of

specimens with the proximal exine scabrate or with fine granulate (?) or punctate (?) sculpture, this ornamentation being usually well developed adjacent to the laesurae. Such specimens, which agree in all other essential features with specimens from the type locality, are present in the assemblages from the Surat Basin, and one is illustrated (Plate 2, Figure 4). *I. marburgensis* differs from *I. punctatus* and *I. crateris* in having smaller lumina that are more irregular in outline.

Distribution.—Evergreen Shale, Hutton Sandstone, Walloon Formation (Surat Basin); Jurassic of Marburg Sandstone (de Jersey 1963); Rhaeto-Liassic of Leigh Creek Coal Measures (Playford and Dettmann 1964).

Genus CADARGASPORITES, New genus

Generic diagnosis.—Spores with polar and equatorial diameters approximately equal. Amb circular or sub-circular. Exine ornamented, except for a sharply defined sub-circular area surrounding laesurae, diameter about half equatorial diameter. Trilete, laesurae extending to margin of proximal smooth area. Ornamentation variable, including granulate, spinulate, baculate, verrucate and reticulate sculptural elements. Exine distinctly thinner (due of absence of outer ornamented layer) in proximal area surrounding laesurae.

Type species.—*Cadargasporites baculatus,* new species, described below.

Remarks.—Genera which resemble *Cadargasporites* in having a smooth area on the proximal surface are *Anapiculatisporites* Potonié and Kremp, *Anaplanisporites* Jansonius and *Setosisporites* (Ibrahim) Potonié and Kremp. The two former differ, however, in having all, or nearly all, of the proximal surface smooth, in contrast to the greater encroachment of ornamentation on the proximal face in the Queensland genus. *Cadargasporites* is also distinguished from those two genera by the sharply defined nature of its proximal smooth area, an area in which the exine is appreciably thinner, because of the absence of the outer ornamented layer. In *Setosisporites* portion of the proximal exine surrounding the sharply defined smooth area, is ornamented, as in *Cadargasporites,* but the sculptural elements consist of branching hair-like processes, significantly different from the less elongate elements in the Queensland genus.

The generic name refers to the Cadarga Creek area, about 40 miles south-west of Mundubbera, in the north-eastern portion of the Surat Basin. Samples from shallow holes, drilled by the Phillips Petroleum Company in this area and referred to as P.S. Charleys Creek Scout Bores in the text and Locality Map (fig. 1), have yielded well preserved specimens of the genus, two of which have been selected as holotypes of two of the three species described below.

Cadargasporites baculatus, new species

Plate 2, Figures 5, 6 and 7; Plate 3, Figures 1, 2 and 3

Diagnosis.—Spores with polar and equatorial diameters approximately equal. Equatorial diameter (based on 37 measured specimens) 40 to 86 microns (majority between 50 and 75 microns). Exine ornamented, except for a sharply defined sub-circular smooth area surrounding laesurae, diameter about half equatorial diameter. Trilete, laesurae, often poorly defined, occasionally with slightly developed lips, extending to margin of proximal smooth area. Ornamentation dominantly baculate, with cylindrical projections, averaging 2 microns in length and 1 micron or less in basal diameter. Area surrounding laesurae smooth, remainder of proximal surface with elements slightly reduced from their equatorial size, grading from baculate to spinulate or granulate. Distal surface usually with gradation in ornamentation from baculate at equator to verrucate or spinulate (diameter of projections 1 to 2 microns) at distal pole; spacing of elements also often showing gradation from more closely packed near equator to more widely spaced (2 to 3 microns apart) around distal pole. Exine about 2 to 3 microns thick at equator; thickness reduced in proximal smooth area.

Holotype (Polar view, proximal, distal and equatorial foci—Plate 2, Figures 5, 6 and 7).—Slide S. 110, stage co-ordinates 39·3, 105·9; equatorial diameter 71 microns. Co-ordinates of lower right-hand corner of cover glass 46·9, 88·5.

Locality.—P.S. Charleys Creek Scout Bore No. 19, 70 ft. to 80 ft.

Figured specimen (Polar view, proximal and distal foci—Plate 3, Figures 1 and 2).—Slide S. 109, stage co-ordinates 29·7, 96·2; equatorial diameter 63 microns. Co-ordinates of lower right-hand corner of cover glass 47·4, 84·8.

Locality.—P.S. Charleys Creek Scout Bore No. 19, 70 ft. to 80 ft.

Figured specimen (Oblique lateral view, Plate 3, Figure 3).—Slide S. 110, stage co-ordinates 39·2, 106·9; dimensions 63 microns (equatorial), 53 microns (polar); co-ordinates of lower-right hand corner of cover glass 46·9, 88·5.

Locality.—P.S. Charleys Creek Scout Bore No. 19, 70 ft. to 80 ft.

Remarks.—*Cadargasporites baculatus* differs from *C. granulatus,* described below, in having dominantly baculate, not dominantly granulate, sculptural elements, and also in having a significantly thicker exine. It also differs from *C. reticulatus,* described below, in having baculate, not reticulate sculpture.

Distribution.—Precipice Sandstone, Evergreen Shale, basal Hutton Sandstone (Surat Basin).

Cadargasporites granulatus, new species

Plate 3, Figures 4, 5, 6 and 7

Diagnosis.—Spores with polar and equatorial diameters approximately equal. Amb circular or sub-circular. Equatorial diameter (based on 11 measured specimens) 43 to 63 microns. Exine ornamented, except for a sharply defined sub-circular area surrounding laesurae, diameter about half equatorial diameter.

Trilete, laesurae, often poorly defined, extending to margin of proximal smooth area. Ornamentation dominantly granulate (occasional rare bacula) with rounded to slightly conical projections 0·5 to 1·5 microns in diameter, about 1 to 3 microns apart, without marked variation in density of pattern or size of elements between equatorial and distal portions of exine. Proximal area, surrounding laesurae, smooth. Exine about 1·5 microns in thickness at equator, thinner in proximal smooth area.

Holotype (Polar view, proximal and distal foci—Plate 3, Figures 5 and 6).—Slide O.D. 1902, stage co-ordinates 46·5, 90·2; equatorial diameter 44 microns. Co-ordinates of lower right-hand corner of cover glass 47·5, 82·1.

Locality.—P.S.Q. Durabilla West No. 1 well, sidewall core No. 5 (4,325 ft.).

Figured specimen (Polar view, proximal and distal foci—Plate 3, Figures 4 and 7).—Slide S. 110, stage co-ordinates 31·0, 88·0; equatorial diameter 48 microns. Co-ordinates of lower right-hand corner of cover glass 46·9, 88·5.

Locality.—P.S. Charleys Creek Scout Bore No. 19, 70 ft. to 80 ft.

Remarks.—*Cadargasporites granulatus* differs from *C. baculatus,* described above, in having dominantly granulate, not dominantly baculate, sculptural elements, and also in having a distinctly thinner exine. It also differs from *C. reticulatus,* described below, in having granulate, not reticulate, sculpture.

Distribution.—Evergreen Shale (Surat Basin).

Cadargasporites reticulatus, new species

Plate 4, Figures 1, 2, 3, 4, 5 and 6; Plate 5, Figure 1

Diagnosis.—Spores with polar and equatorial diameters approximately equal. Amb circular or sub-circular. Equatorial diameter (based on 13 measured specimens) 48 to 77 microns. Exine ornamented, except for a sharply defined sub-circular smooth area surrounding laesurae, diameter about half equatorial diameter. Trilete, laesurae, often poorly defined, extending to margin of proximal smooth area. Ornamentation reticulate (reticulum perfect to imperfect) with polygonal lumina 3 to 6 microns in diameter, muri about 1 micron in width, and about 3 microns high at equator. Exine about 2 to 3 microns in thickness at equator, distinctly thinner (1 micron or less) in proximal smooth area.

Holotype (Polar view, Proximal, distal and equatorial foci—Plate 4, Figures 1, 2 and 3).—Slide O.D. 2208, stage co-ordinates 41·1, 100·0; equatorial diameter 6·9 microns. Co-ordinates of lower right-hand corner of cover glass 47·6, 81·8.

Locality.—Union–Kern–A.O.G. Moonie No. 3 well, 5,233 ft. (sidewall core).

Figured specimen (Polar view, Proximal, distal and equatorial foci—Plate 4, Figures 4, 5 and 6).—Slide S. 87, stage co-ordinates 44·2, 83·8; equatorial diameter 56 microns. Co-ordinates of lower right-hand corner of cover glass 49·6, 76·5.

Locality.—P.S. Charleys Creek Scout Bore No. 20, 430 ft. to 440 ft.

Figured specimen (Equatorial view; Plate 5, Figure 1).—Slide O.D. 2205, stage co-ordinates 44·1, 89·2; dimensions 56 microns (equatorial) × 54 microns (polar). Co-ordinates of lower right-hand corner of cover glass 47·7, 86·6.

Locality.—Union–Kern–A.O.G. Moonie No. 3 well, 5,233 ft. (sidewall core).

Remarks.—The reticulate ornamentation of this species distinguishes it from both *Cadargasporites baculatus* and *C. granulatus,* described above.

Distribution.—Evergreen Shale (Surat Basin).

Genus CINGULATISPORITES Thomson

Cingulatisporites saevus Balme, Emend.

Plate 5, Figures 4, 5 and 6

1957 *Cingulatisporites saevus* Balme. *C.S.I.R.O. Phys. Chem. Surv. Nat. Coal Res., T.C.* 25, p. 26; pl. 4, fig. 57; pl. 5, figs. 58, 59.

1959 *Cingulatisporites granulatus* de Jersey. *Qld Govt Min. J.,* **60,** p. 57, pl. 2, fig. 7.

1963 *Cingulatisporites granulatus* de Jersey. *Qld Geol. Surv. Publ.* 313, p. 6, pl. 1, figs. 11, 13.

Emended diagnosis.—Amb rounded triangular to sub-circular. Spore complex, consisting of a central body surrounded equatorially by a hyaline cingulum 2 to 7 microns wide. Trilete, laesurae extending to the junction of the central body and cingulum. Total diameter (based on 53 measured specimens) 22 to 50 microns. Exine 1 to 2 microns thick; proximal exine smooth; distal exine ornamented with granulate, verrucate or spinose projections, with rounded to pointed extremities; usually closely packed. Basal diameter of projections from 1 to 3 microns, length from 1 to 6 microns in different specimens; projections normally of approximately similar size or showing slight increase in length towards equator in individual specimens. Cingulum smooth or with faint radial striations.

Figured specimen (Plate 5, Figure 5).—Slide S. 109, stage co-ordinates 39·6, 88·8; diameter 33 microns. Co-ordinates of lower right-hand corner of cover glass 47·4, 84·8.

Locality.—P.S. Charleys Creek Scout Bore No. 19, 70 ft. to 80 ft.

Figured specimen (Plate 5, Figure 6).—Slide O.D. 2260, stage co-ordinates 34·0, 89·8; diameter 43 microns. Co-ordinates of lower right-hand corner of cover glass 49·1, 81·9.

Locality.—P.S.Q. Zig Zag No. 1 well, sidewall core No. 8 (1,851 ft.).

Figured specimen (Plate 5, Figure 4).—Slide 199 (Rosewood Coalfield), stage co-ordinates 41·4, 98·8; diameter 35 microns. Co-ordinates of lower right-hand corner of cover glass 48·0, 89·1.

Locality.—Rosewood Coalfield, Bore N.S. 42, 515 ft. 7¼ in. to 522 ft. 1½ in.

Remarks.—Study of a large number of specimens from the Hutton Sandstone has indicated that the specimens described as *C. saevus* Balme 1957 and *C. granulatus* de Jersey 1959 represent end members of a series showing continuous gradation in size and shape of the projections constituting the distal sculpture. Continuous variation also exists in other characters, e.g. the width of the cingulum, and consequently the two taxa are here united. Accordingly the specific diagnosis of *C. saevus* is emended above so as to include the specimens with fine (granulate-spinulate) ornament originally recorded as *C. granulatus,* the latter being then placed in synonymy with the emended *C. saevus.* The specimens figured indicate the range of variation, Plate 5, Figure 4 being of a specimen with fine (granulate-spinulate) ornament (the original holotype of *C. granulatus,* from the Rosewood coalfield), while Plate 5, Figure 6 illustrates a specimen with coarse (spinose) ornament typical of Balme's original *C. saevus.* The other specimen (Plate 5, Figure 5) represents ornamentation intermediate between these extremes. Other specimens observed show gradation in sculpture between those illustrated.

The species is retained in *Cingulatisporites* as it is truly cingulate on the basis of Pocock's definition of the term "cingulum" (Pocock 1961, p. 1235.) As indicated previously (de Jersey 1963, pp. 6, 7) this cingulate character is regarded as having greater fundamental significance than the ornamentation in placing the species in *Cingulatisporites.*

Distribution.—Uppermost Evergreen Shale, Hutton Sandstone, Walloon Formation, Blythesdale Group (Surat Basin); Walloon Coal Measures (Rosewood Coalfield) (de Jersey 1959); Marburg Sandstone (de Jersey 1963); Upper Jurassic of Western Australia (Balme 1957).

Genus POLYCINGULATISPORITES (Simoncsics and Kedves) Playford and Dettmann

Polycingulatisporites crenulatus Playford and Dettmann

Plate 5, Figure 3

Figured specimen (Plate 5, Figure 3).—Slide O.D. 2141, stage co-ordinates 33·3, 98·7; diameter 46 microns. Co-ordinates of lower right-hand corner of cover glass 47·5, 83·0.

Locality.—Phillips–Sunray Cecil Plains No. 1 Well, sidewall core No. 9 (2,851 ft.).

Remarks.—The specimens recorded here have a range in diameter from 41 to 66 microns (based on 16 measured specimens). They differ slightly from those figured by Playford and Dettmann (1964, pl. 3, figs. 7–10) in having a more rounded sub-circular outline, and also in having a slightly smaller ridge at the distal pole (external diameter 10 to 16 microns as compared with 20 to 24 microns in the specimens figured by Playford and Dettmann). These slight differences are, however, regarded as being within the range of variation of *P. crenulatus.* Two specimens including the specimen figured (Plate 5, Figure 3) which are representative of the specimens recorded, have been examined by those authors who regard them as being within the limits of variation of *P. crenulatus* (Verbal communication).

Distribution.—Upper Precipice Sandstone, Evergreen Shale, Hutton Sandstone, ? Walloon Formation (Surat Basin); Rhaeto–Liassic of Leigh Creek Coal Measures (Playford and Dettmann 1964).

Polycingulatisporites mooniensis, new species

Plate 5, Figures 7, 8 and 9

Diagnosis.—Amb sub-triangular, outline slightly to distinctly rounded. Diameter (based on 26 measured specimens) 20 to 36 microns. Trilete mark indistinct to well defined; where evident laesurae extend about two-thirds spore radius, occasionally with slight thickening of lips. Equatorial thickening (cingulum) present, width about 2 microns. Distal surface with two low concentric ridges, about 1·5 to 2 microns wide, outline slightly to distinctly rounded triangular to sub-circular. Inner ridge surrounding distal pole, external diameter 3 to 10 microns; outer ridge located at about two-thirds spore radius from distal pole. Ridges occasionally exhibit somewhat sinuous outline, possibly due to wrinkling in preservation. Proximal exine smooth, distal exine smooth to scabrate. Exine (apart from ridges) relatively thin (pale yellow to colourless).

Holotype (Plate 5, Figure 7).—Slide O.D. 2,114, stage co-ordinates 33·5, 85·9; diameter 26 microns. Co-ordinates of lower right-hand corner of cover glass 48·3, 81·9.

Locality.—P.S.Q. Waggaba No. 1 well, sidewall core No. 9 (3,688 ft.).

Figured specimen (Plate 5, Figure 8).—Slide O.D. 1961, stage co-ordinates 42·0, 87·7; diameter 30 microns. Co-ordinates of lower right-hand corner of cover glass 47·4, 83·8.

Locality.—P.S.Q. Durabilla West No. 1 well, sidewall core No. 13 (4,036 ft.).

Figured specimen (Plate 5, Figure 9).—Slide O.D. 2159, stage co-ordinates 30·9, 101·9; diameter 25 microns. Co-ordinates of lower right-hand corner of cover glass 47·6, 87·2.

Locality.—Phillips–Sunray Cecil Plains No. 1 well, sidewall core No. 6 (3,742 ft.).

Remarks.—This species is significantly smaller than other species of *Polycingulatisporites,* except

P. densatus (de Jersey) Playford and Dettmann, which is of comparable size. It differs from that species in having thickening in the distal polar region consisting of a ring structure, not an area of uniform thickening as in *P. densatus*. In addition *P. mooniensis* has a tendency to a sub-triangular amb, as distinguished from *P. densatus*, which, though it does include specimens which are rounded sub-triangular in outline, is more normally sub-circular.

The specific name has reference to the Moonie oilfield, the species having been first observed in core samples of the Precipice Sandstone from the U.K.A. Moonie No. 3 well.

Distribution.—Precipice Sandstone, lower Evergreen Shale (Surat Basin).

Genus DUPLEXISPORITES (Déak) Playford and Dettmann

Duplexisporites gyratus Playford and Dettmann

Plate 5, Figure 10

Figured specimen (Plate 5, Figure 10).—Slide O.D. 1901, stage co-ordinates 44·2, 98·1; diameter 33 microns. Co-ordinates of lower right-hand corner of cover glass 48·5, 88·3.

Locality.—P.S.Q. Durabilla West No. 1 well, sidewall core No. 5 (4,325 ft.).

Remarks.—The specimens from the Surat Basin agree, in all essential features, with the diagnosis of Playford and Dettmann (1964).

Distribution.—Precipice Sandstone, lower Evergreen Shale (Surat Basin); Rhaeto–Liassic of Leigh Creek Coal Measures (Playford and Dettmann 1964); Upper Triassic of Bundamba Group (de Jersey 1964).

Genus STAPLINISPORITES Pocock

Staplinisporites caminus (Balme) Pocock

Plate 5, Figure 2

Description (Dettmann 1963, p. 51).—"Microspores trilete, planoconvex, the distal surface convex; amb convexly triangular to sub-circular. Laesurae straight or weakly sinuous, extending to amb, and with thin (c. 1 micron thick), low lips. Exine 2 microns thick, smooth or faintly granulate proximally. Equatorial region of distal surface with low (c. 1 micron high), radially disposed elevations which extend from equator to a narrow, low, circumpolar ridge; ridge concentric with, and two-thirds radius of, amb. Distal exine enclosed within circumpolar ridge faintly granulate and thickened in a circular area (8–10 microns in diameter) about the pole.

Dimensions.—Equatorial diameter (2 specimens) 39, 45 microns."

Figured specimen (Plate 5, Figure 2).—Slide S. 214, stage co-ordinates 43·6, 91·3; diameter 41 microns. Co-ordinates of lower right-hand corner of cover glass 47·3, 84·4.

Locality.—Q.M.D. Carnarvon Range No. 5, 39 ft. to 42 ft.

Remarks.—The specimens from the Surat Basin have all the essential diagnostic characters of this species and resemble closely the figures of Balme (1957, pl. 5, figs. 62, 63) and Dettmann (1963, pl. 9, figs. 8 and 9). Their range in equatorial diameter (based on 6 measured specimens) is from 35 to 41 microns. The thickened area at the distal pole exhibits some variation in size, shape and distinctness; the distal exine within the circumpolar ridge also varies from distinctly granulate to almost smooth. These features, however, show variation in both Balme's and Dettmann's figures.

The species has been recorded by Balme (1957, Table 3) from the Upper Jurassic of Western Australia and by Dettmann (1963, p. 51) from the Lower Cretaceous of South-Eastern Australia. Its presence near the base of the Hutton Sandstone suggests that its stratigraphic range extends at least down into the Middle Jurassic.

Distribution.—Upper Evergreen Shale, lower Hutton Sandstone (Surat Basin), Upper Jurassic of Western Australia (Balme 1957); Lower Cretaceous of South-Eastern Australia (Dettmann 1963).

Genus NEVESISPORITES, new genus

Generic diagnosis.—Amb circular or sub-circular. Trilete, distinct laesurae extend to, or almost to, equator. Spore with distinct equatorial thickening (cingulum). Distal exine smooth or faintly roughened. Proximal exine ornamented with granules, verrucae, spinules or bacula. Extent of sculpture variable, but always present on inter-radial areas adjacent to laesurae.

Type species.—*Nevesisporites vallatus*, new species, described below.

Remarks.—This new genus is named after R. Neves, who drew attention to the occurrence of spores with proximal ornament, when describing *Discernisporites* from the Carboniferous of North Staffordshire, England (Neves 1958, p. 4). It differs from *Discernisporites* in having distinct equatorial thickening, in having a circular, not a triangular or sub-triangular amb, and in not normally having the sculpture confined to a triangular area around the proximal pole. The genus is also distinguished from *Foraminisporis* Krutzsch by the absence of the well defined distal ornament of that genus. *Foraminisporis* also has the proximal ornament usually confined to the centre of each proximal face.

Nevesisporites vallatus, new species

Plate 5, Figures 11, 12, 13, 14 and 15; Plate 6, Figures 1 and 2

Diagnosis.—Amb circular or sub-circular. Diameter (based on 62 measured specimens) 35 to 47 microns. Trilete; distinct laesurae, often with

slight development of lips (1 micron) extend to, or almost to, the equator. One or more of laesurae bifurcating before reaching equator, in some specimens. Distinct equatorial thickening (cingulum) about 2 to 3 microns in width. Distal exine smooth or faintly roughened. Cingulum smooth. Proximal exine ornamented with granules 0·5 to 1·5 microns in diameter, grading into baculate projections about 2 microns in length and 1 micron in basal diameter, set about 1 micron apart. Sculptural elements tending to be larger adjacent to laesurae; in some cases showing a radial arrangement about the centre of each inter-radial area. Extent of ornamentation variable; whole of proximal exine may be covered; when ornament is reduced proximal exine adjacent to equator is smooth; in extreme cases ornament is reduced to rows of granules or bacula adjacent to laesurae on inter-radial areas.

Holotype (Proximal and distal foci—Plate 5, Figures 11, 12).—Slide O.D. 1995, stage co-ordinates 33·1, 98·9; diameter 40 microns. Co-ordinates of lower right-hand corner of cover glass 46·9, 88·6.

Locality.—P.S.Q. Durabilla West No. 1 well, sidewall core No. 9 (4,171 ft.).

Figured specimen (Proximal and distal foci—Plate 5, Figures 13 and 14).—Slide O.D. 1996, stage co-ordinates 39·9, 100·2; diameter 40 microns. Co-ordinates of lower right-hand corner of cover glass 47·6, 85·3.

Locality.—P.S.Q. Durabilla West No. 1 well, sidewall core No. 9 (4,171 ft.).

Figured specimen (Proximal focus; Plate 5, Figure 15).—Slide O.D. 1996, stage co-ordinates 44·8, 93·5; diameter 38 microns. Co-ordinates of lower right-hand corner of cover glass 47·6, 85·3.

Locality.—P.S.Q. Durabilla West No. 1 well, sidewall core No. 9 (4,171 ft.).

Figured specimen (Proximal focus; Plate 6, Figure 2).—Slide O.D. 1995, stage co-ordinates 41·9, 93·2; diameter 40 microns. Co-ordinates of lower right-hand corner of cover glass 46·9, 88·6.

Locality.—P.S.Q. Durabilla West No. 1 well, sidewall core No. 9 (4,171 ft.).

Figured specimen (Proximal focus; Plate 6, Figure 1).—Slide O.D. 1994, stage co-ordinates 33·9, 101·2; diameter 40 microns. Co-ordinates of lower right-hand corner of cover glass 47·8, 86.5.

Locality.—P.S.Q. Durabilla West No. 1 well, sidewall core No. 9 (4,171 ft.).

Remarks.—The illustrations (Plate 5, Figures 11–15; Plate 6, Figures 1, 2) indicate the variation in the extent of proximal sculpture and in the size of the sculptural elements. This variation in sculpture, which is allowed for in the specific diagnosis, appears to represent a continuous gradation and it seems unlikely that subdivision of the species into lesser taxonomic units will be possible. In one specimen (Plate 5, Figure 14) the distal exine has a finely pitted appearance, possibly as a result of corrosion; all other specimens examined have smooth distal exines.

The specific name is based on the resemblance in appearance of the rows of baculate projections along the laesurae to rows of stakes in palisades (Latin *vallus* = post or stake used to form palisades in fortification).

Distribution.—Evergreen Shale, Hutton Sandstone (Surat Basin).

Division PTERIDOSPERMOPHYTA

Family CORYSTOSPERMACEAE

Genus ALISPORITES (Daugherty) Potonié and Kremp

Alisporites australis de Jersey

Plate 6, Figure 5

Figured specimen (Plate 6, Figure 5).—Slide O.D. 1464, stage co-ordinates 32·1, 95·2; total span 71 microns. Co-ordinates of lower right-hand corner of cover glass 46·1, 90·9.

Locality.—Union–Kern–A.O.G. Yarrill Creek No. 1 well, Core 5, 3,104 ft.

Remarks.—The specimen figured (Plate 6, Figure 5) has a well defined colpus, indicating its affinity with the Corystospermaceae, and also all the other essential diagnostic characters of *A. australis* (de Jersey 1962, pp. 8 and 9). *A. australis* is a species of dispersed pollen very similar in morphology to the pollen of *Pteruchus johnstoni* (Feistmantel) Townrow, which from evidence of association and cuticle structure, is regarded by Townrow (1962, p. 312) as likely to be the microsporophyll of the leaf species *Dicroidium odontopteroides*. The presence of *A. australis* in these sediments in the Surat Basin thus suggests an extension of the range of these species from Triassic into Jurassic in Queensland.

Distribution.—Precipice Sandstone, Evergreen Shale, Hutton Sandstone (Surat Basin); Triassic of Ipswich Coal Measures (de Jersey 1962); Upper Triassic of Bundamba Group (de Jersey 1964); Rhaeto–Liassic of Leigh Creek Coal Measures (Playford and Dettmann 1964).

Alisporites sp. 1 de Jersey

Plate 6, Figure 7

Figured Specimen (Plate 6, Figure 7).—Slide O.D. 2229, stage co-ordinates 35·0, 88·2; total span 101 microns. Co-ordinates of lower right-hand corner of cover glass 47·8, 83·4.

Locality.—P.S.Q. Tinker Creek No. 1 well, sidewall core No. 7 (3,961 ft.).

Remarks.—The specimen figured (Plate 6, Figure 7), on the basis of its coarse bladder ornament, ornamented corpus with a sub-circular outline and relatively large size, can be grouped with the specimens recorded from the Ipswich Coal Measures (de Jersey 1962, p. 9) as *Alisporites* sp. 1. As previously indicated, these pollens closely resemble the grains of *Pteruchus simmondsi,* and thus provide further evidence on the occurrence of *Pteruchus*-type pollens in the Jurassic of Queensland. The specimen is also comparable with a grain figured by Dettmann (1963, pl. 25, fig. 3) as *Alisporites grandis* (Cookson) Dettmann.

Distribution.—Evergreen Shale, Walloon Formation (Surat Basin), Ipswich Coal Measures (de Jersey 1962).

Family CAYTONIACEAE

Genus VITREISPORITES (Leschik) Jansonius

Vitreisporites pallidus (Reissinger) Nilsson

Plate 6, Figure 3

Figured specimen (Plate 6, Figure 3).—Slide O.D. 2118, stage co-ordinates 44·2, 98·4; total span 31 microns. Co-ordinates of lower right-hand corner of cover glass 46·5, 82·6.

Locality.—P.S.Q. Waggaba No. 1 well, sidewall core No. 9 (3,688 ft.).

Remarks.—Pollen grains from the Walloon Coal Measures, Ipswich Coal Measures and Marburg Sandstone have previously been recorded as *Vitreisporites subtilis* (de Jersey 1959, p. 361; 1962, p. 11; 1963, p. 8). This species was distinguished from *Vitreisporites pallidus* (Reissinger) Nilsson by absence of distinct bladder ornament which is a feature of the latter species. However, study of a large number of specimens from the Surat Basin has indicated that the bladder ornamentation is a variable feature, being apparently dependent on preservation and maceration technique. Accordingly *Vitreisporites subtilis* de Jersey is now regarded as a synonym of *V. pallidus* (Reissinger) Nilsson. Potonié (1960, p. 77) regarded *V. pallidus* as a synonym of the genotype, *V. signatus* Leschik, but Pocock (1962, p. 58) considered the species to be distinct. In view of the presence of a vestigial trilete mark in Leschik's species (from the European Triassic), a feature which has not been observed in the Jurassic species, it seems advisable to regard *V. pallidus* and *V. signatus* as distinct until further evidence is available.

Distribution.—Precipice Sandstone, Evergreen Shale, Hutton Sandstone, Walloon Formation, Blythesdale Group (Surat Basin); Jurassic of Walloon Coal Measures (de Jersey 1959); Marburg Sandstone (de Jersey 1963); Rhaeto–Liassic of Leigh Creek Coal Measures (Playford and Dettmann 1964); Jurassic and Lower Cretaceous of Western Australia (Balme 1957); widely distributed in Jurassic of Europe and North America.

MONOCOLPATE POLLEN GRAINS

Genus CYCADOPITES (Wodehouse) Wilson and Webster

Cycadopites nitidus (Balme) de Jersey

Remarks.—This species has recently (de Jersey 1964) been transferred from *Ginkgocycadophytus* to *Cycadopites,* following Jansonius (1962, p. 80), who regarded *Ginkgocycadophytus* Samoilovitch 1953 as a synonym of *Cycadopites* (Wodehouse 1933) Wilson and Webster 1946.

Distribution.—Precipice Sandstone, Evergreen Shale, Hutton Sandstone, Walloon Formation, Blythesdale Group (Surat Basin); Jurassic of Walloon Coal Measures (de Jersey 1959), Marburg Sandstone (de Jersey 1963); Triassic of Ipswich Coal Measures (de Jersey 1962); Upper Triassic of Bundamba Group (de Jersey 1964); Rhaeto-Liassic of Leigh Creek Coal Measures (Playford and Dettmann 1964); Jurassic and Lower Cretaceous of Western Australia (Balme 1957).

? Division CONIFEROPHYTA

Genus ALISPORITES (Daugherty) Potonié and Kremp

Alisporites lowoodensis de Jersey

Plate 6, Figure 4

Figured specimen (Plate 6, Figure 4).—Slide O.D. 2208, stage co-ordinates 33·2, 94·4; total span 63 microns. Co-ordinates of lower right-hand corner of cover glass 47·6, 81·7.

Locality.—Union–Kern–A.O.G. Moonie No. 3 well, 5,233 ft. (sidewall core).

Remarks.—This species is particularly abundant (65%) in a sample from 5,233 ft. (sidewall core), from the Union–Kern–A.O.G. Moonie No. 3 well. Measurements of 24 specimens from this sample show size ranges of: total span 50 to 67 microns, length of corpus 22 to 37 microns, breadth of corpus 25 to 37 microns, length of sacci 29 to 40 microns, breadth of sacci 20 to 30 microns. These dimensions show a similar pattern to those determined for specimens from the Marburg Sandstone (de Jersey 1963, p. 10).

Distribution.—Evergreen Shale, Hutton Sandstone (Surat Basin); Marburg Sandstone (de Jersey 1963).

Division CONIFEROPHYTA

Genus INAPERTUROPOLLENITES Thomson and Pflug

Remarks.—Manum (1962, pp. 17, 39) has discussed the taxonomy of *Inaperturopollenites* and *Laricoidites.* He has clearly demonstrated (*a*) that *Laricoidites* is only poorly distinguished from *Inaperturopollenites* and (*b*) that *Inaperturopollenites* has chronological priority over *Laricoidites,* not vice versa,

as claimed by Potonié. The writers are in agreement with Manum's conclusions, as pollen grains of this type do not show sufficient variation to warrant use of two separate generic names. Consequently the species which, following Potonié, was transferred to a new combination, *Laricoidites turbatus* (de Jersey 1963, p. 9) is here restored to its original combination, *Inaperturopollenites turbatus*. Similarly *Inaperturopollenites reidi* has recently (de Jersey 1964) been restored to its original combination.

Inaperturopollenites turbatus Balme

1957 *Inaperturopollenites turbatus* Balme, *C.S.I.R.O. Fuel Research, T.C.* 25, p. 31, pl. 7, figs. 85, 86; pl. 8, fig. 87.

1963 *Laricoidites turbatus* (Balme) de Jersey. *Geol. Surv. Qld Publ.* 313, p. 9; pl. 2, fig. 6.

Distribution.—Upper Evergreen Shale, Hutton Sandstone, Walloon Formation, Blythesdale Group (Surat Basin); Marburg Sandstone (de Jersey 1963); Jurassic of Western Australia (Balme 1957).

Inaperturopollenites reidi de Jersey

1959 *Inaperturopollenites reidi* de Jersey. *Qld Govt Min. J.* **60**, p. 362; pl. 3, fig. 7.

1962 *Laricoidites reidi* (de Jersey) de Jersey. *Geol. Surv. Qld Publ.* 307, p. 13; pl. 6, fig. 6.

1963 *Laricoidites reidi* (de Jersey) de Jersey. *Geol. Surv. Qld Publ.* 313, p. 8.

Distribution.—Precipice Sandstone, Evergreen Shale, Hutton Sandstone, Walloon Formation, Blythesdale Group (Surat Basin); Jurassic of Walloon Coal Measures (Rosewood Coalfield) (de Jersey 1959); Marburg Sandstone (de Jersey 1963); Triassic of Ipswich Coal Measures (de Jersey 1962); Upper Triassic of Bundamba Group (de Jersey 1964).

Genus CLASSOPOLLIS (Pflug) Pocock and Jansonius, Emend.

Emended diagnosis.—Pollen grains; distally monoporate, ovoid, spherical, or flatly acorn-shaped; exine two-layered; exoexine absent or much reduced over a circular area surrounding the distal pole, and absent or reduced over a triangular area with its centre at the proximal pole; intexine frequently bearing a reduced trilete scar, which has no germinal function, at the proximal pole; exine with an equatorial girdle which is formed by a belt of thickening, or by parallel striations, or by a combination of both.

Type species.—*Classopollis classoides* Pflug, 1953.

Remarks.—The generic diagnosis given by Pocock and Jansonius (1961, p. 443) is here emended so as to include grains such as *Classopollis simplex,* with a smooth equatorial girdle, described below. Because of this feature the species could not be included in *Circulina* Maljavikina as interpreted by Klaus (1960) or in *Classopollis* (Pflug) Pocock and Jansonius. The genera, as interpreted by these authors, differ in that the latter has (1) an equatorial girdle (2) parallel striations or granules in a parallel pattern on the girdle (3) (usually) well developed exine ornament, which features are lacking in *Circulina.* The existence of a species with a thickened equatorial girdle, without striations, thus represents an intermediate stage between *Classopollis* and *Circulina.* Consequently the presence of this species is suggestive of the development of the Jurassic *Classopollis* from the dominantly Triassic *Circulina.*

Four courses of action are therefore possible:—

(1) To unite the two genera.

(2) To widen the generic diagnosis of *Circulina* to include this species.

(3) To widen the generic diagnosis of *Classopollis* to include this species.

(4) To propose a new, monotypic genus.

The third course has been adopted as it is considered that the development of an equatorial girdle represented a fundamental stage in the development of pollen grains of this type, and that its presence is more significant, morphologically, than the presence of parallel striations upon it.

Classopollis classoides (Pflug) Pocock and Jansonius

Plate 7, Figures 1, 2 and 3

Figured specimen (Polar view, Plate 7, Figure 1).—Slide S. 45, stage co-ordinates 39·8, 94·3; diameter 36 microns. Co-ordinates of lower right-hand corner of cover glass 46·8, 89·0.

Locality.—P.S. Charleys Creek Scout Bore No. 4, 120 ft. to 130 ft.

Figured specimen (Polar view, Plate 7, Figure 2).—Slide S. 109, stage co-ordinates 32·4, 97·0; diameter 31 microns. Co-ordinates of lower right-hand corner of cover glass 47·4, 84·8.

Locality.—P.S. Charleys Creek Scout Bore No. 19, 70 ft. to 80 ft.

Figured specimen (Equatorial view, Plate 7, Figure 3).—Slide S. 120, stage co-ordinates 44·8, 103·8; dimensions 31 microns (equatorial) × 30 microns (polar). Co-ordinates of lower right-hand corner of cover glass 46·4, 91·3.

Locality.—P.S. Charleys Creek Scout Bore No. 7, 30 ft. to 40 ft.

Remarks.—The specimens from the Surat Basin have all the essential diagnostic characters of this species. They have a slightly different size range (23 to 38 microns in equatorial diameter as compared with 21 to 33 microns quoted by Pocock and Jansonius (1961, p. 443)). In view of the close similarity in all other features, this slight size difference cannot be regarded as having taxonomic significance and should instead be interpreted as extending the

known size range of the species. Specimens of *Classopollis* from the Marburg Sandstone have previously been recorded (de Jersey 1963, p. 9) as *Classopollis torosus* (Reissinger) Couper. In doing so, the writer followed Couper (1958, p. 157) who regarded *C. classoides* as a synonym of *C. torosus,* which he interpreted broadly. The detailed work of Pocock and Jansonius, however indicates that the species should be regarded as distinct (Pocock and Jansonius 1961, pp. 441, 442). Consequently the specimens from the Marburg Sandstone, which agree in essential diagnostic characters with those from the Surat Basin, should now be recorded as *C. classoides.*

Distribution.—Precipice Sandstone, Evergreen Shale, Hutton Sandstone, Walloon Formation, ? Blythesdale Group (Surat Basin); Jurassic of Marburg Sandstone (de Jersey 1963); Rhaeto-Liassic of Leigh Creek Coal Measures (Playford and Dettmann 1964); widespread in Jurassic of North America and Europe.

Classopollis simplex, new species

Plate 7, Figures 4, 5 and 6

Diagnosis.—Amb circular; equatorial diameter (based on 13 measured specimens) 18 to 26 microns; polar diameter (one specimen) 14 microns. Exine monoporate, with a circular distal pore (tenuitas) about 4 or 5 microns in diameter; vestigial trilete dehiscence represented on the proximal surface by a dehiscence triangle with straight or slightly concave sides about 5 to 7 microns in length or by a triradiate mark with short narrow laesurae. Exine two-layered; intexine thin, smooth, continuous over whole area of grain; exoexine divided into two portions by a narrow band of exinal thinning slightly distal to the equator (rimula or distal tenuitas). Equatorial girdle distinctly thickened, smooth and about 5 microns in width in equatorial view; in polar view smooth or with faint radiating ornament. Remainder of exoexine smooth or with faint granulate (?) or punctate (?) ornamentation. Distal exine (apart from distal pore) thickened or deeply pigmented, yellowish brown to dark brown in transmitted light.

Holotype (Polar view, Plate 7, Figure 4).—Slide O.D. 2116, stage co-ordinates 34·2, 93·4; diameter 25 microns. Co-ordinates of lower right-hand corner of cover glass 46·7, 84·4.

Locality.—P.S.Q. Waggaba No. 1 well, sidewall core No. 9 (3,688 ft.).

Figured specimen (Polar view, Plate 7, Figure 5).—Slide O.D. 2110, stage co-ordinates 33·6, 91·8; diameter 25 microns. Co-ordinates of lower right-hand corner of cover glass 46·3, 85·8.

Locality.—P.S.Q. Waggaba No. 1 well, sidewall core No. 11 (3,600 ft.).

Figured specimen (Slightly laterally tipped, Plate 7, Figure 6).—Slide O.D. 2117, stage co-ordinates 38·9, 96·7; diameter 20 microns. Co-ordinates of lower right-hand corner of cover glass 47·7, 86·6.

Locality.—P.S.Q. Waggaba No. 1 well, sidewall core No. 9 (3,688 ft.).

Remarks.—This species is distinguished from other species of *Classopollis* by the absence of striations on the equatorial girdle (apparent in laterally tipped specimens—see Plate 7, Figure 6); the genus is emended as discussed above to include it. The specific name refers to the simple, unornamented nature of the equatorial girdle and to the simplicity of construction as compared with other species of *Classopollis* (Latin *simplex* = simple, without ornament).

Distribution.—Precipice Sandstone, lower Evergreen Shale (Surat Basin).

Genus TSUGAEPOLLENITES Potonié and Venitz, emend. Potonié 1958

Remarks.—Dettmann (1963, pp. 99, 100) has discussed the taxonomy of this genus and has shown that *Callialasporites* Dev 1961 is a synonym. Thus the species recorded from the Marburg Sandstone (de Jersey 1963, p. 9) as *C. dampieri* and *C. segmentatus* have been placed, as new combinations, in *Tsugaepollenites.*

Tsugaepollenites dampieri (Balme) Dettmann

Plate 7, Figure 8

Figured specimen (Plate 7, Figure 8).—Slide S. 209, stage co-ordinates 35·5, 86·6; diameter 66 microns. Co-ordinates of lower right-hand corner of cover glass 48·7, 86·1.

Locality.—P.S. Charleys Creek Scout Bore No. 20, 40 ft. to 50 ft.

Distribution.—Upper Evergreen Shale, Hutton Sandstone, Walloon Formation, Blythesdale Group (Surat Basin); Jurassic of Walloon Coal Measures (Rosewood coalfield) (de Jersey 1959), Marburg Sandstone (de Jersey 1963); Jurassic, Cretaceous and Eocene of Western Australia (Balme 1957); Aptian-Albian of Papua (Balme 1957); Upper Mesozoic of south-eastern Australia (Dettmann 1963); widely distributed in Upper Mesozoic of India, Canada and Europe.

Tsugaepollenites segmentatus (Balme) Dettmann

Plate 7, Figure 9

Figured specimen (Plate 7, Figure 9).—Slide S. 214, stage co-ordinates 40·0, 95·8; diameter 58 microns. Co-ordinates of lower right-hand corner of cover glass 47·4, 84·4.

Locality.—Q.M.D. Carnarvon Range No. 5, 39 ft. to 42 ft.

Distribution.—Upper Evergreen Shale, Hutton Sandstone, Walloon Formation, Blythesdale Group (Surat Basin); Jurassic of Walloon Coal Measures (Rosewood Coalfield) (de Jersey 1959), Marburg Sandstone (de Jersey, 1963); Jurassic of Western Australia (Balme 1957).

Tsugaepollenites trilobatus (Balme) Dettmann

Plate 7, Figure 10

Figured specimen (Plate 7, Figure 10).—Slide O.D. 2267, stage co-ordinates 30·1, 95·4; total diameter 59 microns. Co-ordinates of lower right-hand corner of cover glass 47·1, 86·9.

Locality.—P.S.Q. Zig Zag No. 1 well, Core 1 (1,962 ft. 9 in.).

Distribution.—Hutton Sandstone, Walloon Formation, Blythesdale Group (Surat Basin); Upper Jurassic and Lower Cretaceous of Britain (Lantz 1958, Hughes and Couper 1958), Germany (Döring 1961) and Western Australia (Balme 1957); Middle and Upper Jurassic of Canada (Pocock 1962); Lower Cretaceous of India (Dev 1961); Upper Mesozoic of south-eastern Australia (Dettmann 1963).

Genus PERINOPOLLENITES Couper

Perinopollenites elatoides Couper

Plate 6, Figures 9 and 10

1958 *Perinopollenites elatoides* Couper. *Palaeontographica*, **103B**, p. 152, pl. 27, figs. 9–11.

1963 *Perotriletes tenuis* de Jersey. *Geol. Surv. Qld Publ.* 313, p. 7, pl. 1, figs. 9, 10, 12.

Figured specimen (showing pore (?), Plate 6, Figure 9).—Slide O.D. 1939, stage co-ordinates 42·1, 98·4; diameter 40 microns (central body 30 microns). Co-ordinates of lower right-hand corner of cover glass 48·7, 83·3.

Locality.—P.S.Q. Durabilla West No. 1 well, sidewall core No. 18 (3,732 ft.).

Figured specimen (Plate 6, Figure 10).—Slide O.D. 2001, stage co-ordinates 34·0, 94·5; diameter 38 microns (central body 23 microns). Co-ordinates of lower right-hand corner of cover glass 46·1, 86·5.

Locality.—P.S.Q. Durabilla West No. 1 well, sidewall core No. 7 (4,234 ft.).

Remarks.—Specimens described as *Perotriletes tenuis* from the Marburg Sandstone (de Jersey 1963, p. 7) resemble *Perinopollenites elatoides* Couper, in morphological features, except for the occasional presence of a trilete mark in the former, which was not recorded by Couper, and the presence of a pore in some specimens of Couper's species. However study of a large number of specimens from the Surat Basin, which are obviously conspecific with those from the Marburg Sandstone, indicates that the trilete mark occasionally observed is vestigial, not functional, and that there are indications of the presence of a pore in a few specimens (for example the specimen figured in Plate 6, Figure 9). Accordingly *P. tenuis* is now regarded as a synonym of *P. elatoides* Couper. The presence of a vestigial trilete mark in *P. elatoides* has also been reported by Pocock (1962, p. 60). The dimensions of the specimens from the Surat Basin agree closely with those based on material from the Marburg Sandstone, which were: Total diameter 25 to 50 microns, diameter of central body 17 to 36 microns.

Distribution.—Precipice Sandstone, Evergreen Shale, Hutton Sandstone, Walloon Formation (Surat Basin); Marburg Sandstone (de Jersey 1963), Jurassic and Lower Cretaceous of Great Britain (Couper 1958); Jurassic and Lower Cretaceous of Canada (Pocock 1962).

Genus INDUSIISPORITES Leschik

Indusiisporites parvisaccatus (de Jersey) de Jersey

Plate 6, Figures 6 and 8

Figured specimen (Plate 6, Figure 6).—Slide S. 109; stage co-ordinates 38·8, 90·6; dimensions 49 × 43 microns. Co-ordinates of lower right-hand corner of cover glass 47·4, 84·8.

Locality.—P.S. Charleys Creek Scout Bore No. 19, 70 ft. to 80 ft.

Figured specimen (Plate 6, Figure 8).—Slide O.D. 2052, stage co-ordinates 38·7, 96·9; dimensions 49 × 36 microns. Co-ordinates of lower right-hand corner of cover glass 47·6, 82·9.

Locality.—P.S.Q. Waggaba No. 1 well, sidewall core No. 17 (3,323 ft.).

Remarks.—The specimens recorded here agree in essential diagnostic characters with *I. parvisaccatus*, previously described from the Walloon Coal Measures (de Jersey 1959, p. 363; pl. 3, fig. 10) and Marburg Sandstone (de Jersey 1963, p. 10; pl. 3, fig. 7). Some of the specimens from the Surat Basin exhibit structures within the bladders suggestive of an incomplete coarse reticulum. One such specimen is figured (Plate 6, Figure 8). Such structures may be the remains of tissue within the bladders which is normally partially or completely destroyed by the maceration technique employed.

Distribution.—Precipice Sandstone, Evergreen Shale, Hutton Sandstone, Walloon Formation, Blythesdale Group (Surat Basin); Marburg Sandstone (de Jersey 1963), Walloon Coal Measures of Rosewood Coalfield (de Jersey 1959).

Genus PODOSPORITES Rao

Podosporites sp.

Plate 7, Figure 7

Description.—Pollen grains, trisaccate. Corpus sub-circular in polar view, diameter (based on 13 measured specimens) 30 to 58 microns. Exine thin (proximal cap about 1·5 microns in thickness), with indistinct fine ornamentation, sulcus smooth or faintly granulate. Sacci, about 1 micron in thickness, ornamented with a fine indistinct reticulum, sub-oval to semi-circular or sub-triangular, length 18 to 36 microns, breadth 10 to 20 microns.

Figured specimen (Plate 7, Figure 7).—Slide O.D. 2042, stage co-ordinates 33·8, 95·9; diameter 40 microns. Co-ordinates of lower right-hand corner of cover glass 46·4, 86·0.

Locality.—P.S.Q. Waggaba No. 1 well, sidewall core No. 18 (3,220 ft.).

Remarks.—The specimens recorded are of stratigraphic interest, as they are the earliest representatives of trisaccate pollens of this type in the Queensland Mesozoic sequence. Two trisaccate species described from the Mesozoic of Australia are *Microcachryidites antarcticus* Cookson and *Podosporites microsaccatus* (Couper) Dettmann. This grains recorded here differ from *M. antarcticus* in being appreciably larger, many of the specimens being outside the size ranges quoted by Cookson (1947, p. 132) and Dettmann (1963, p. 103). In addition, the occurrence of forms with more than three bladders which is a feature of *M. antarcticus* (Balme 1957, p. 34; Dettmann 1963, pl. 26) has not been observed in the Queensland material. Relatively large grains, occurring in the Middle Bajocian of Western Australia, and assigned by Balme to *M. antarcticus,* also differ from the Queensland specimens in having a sharply defined regular reticulum on their bladders. With regard to *P. microsaccatus,* the sub-triangular corpus and small, rudimentary bladders (with radial thickenings) readily distinguish that species from the grains recorded here. The genotype *P. tripakshi* Rao (Rao 1943, p. 175) comprises grains which are relatively smaller, and have thicker exines than these Queensland specimens. *Podocarpidites ohikaensis,* Couper from the Jurassic of New Zealand (Couper 1953, p. 37) differs in having a more coarsely sculptured proximal cap.

Comparison with published descriptions thus suggests that these Queensland specimens are distinct from previously described species. A new specific name has not been proposed as only a small number of specimens have been available for study. Because of the wide variation known in previously described species of trisaccate pollen of this type, study of a large number of well preserved specimens would be necessary to define a new species adequately.

Distribution.—Evergreen Shale (Surat Basin).

SPORES AND POLLEN GRAINS—INCERTAE SEDIS

Genus CIRCULISPORITES de Jersey

Circulisporites parvus de Jersey

Remarks.—Rare specimens of this species, previously recorded from the Ipswich Coal Measures (de Jersey 1962, p. 15; pl. 5, figs. 13, 14 and 15) and Marburg Sandstone (de Jersey 1963, p. 11) have been found in samples from the Surat Basin.

Distribution.—Evergreen Shale, Hutton Sandstone (Surat Basin); Triassic of Ipswich Coal Measures (de Jersey 1962); Upper Triassic of Bundamba Group (de Jersey 1964); Jurassic of Marburg Sandstone (de Jersey 1963).

5. AGE OF THE MICROFLORAS

Evidence on the age of the microfloras from the Jurassic of the Surat Basin is based, almost entirely, on correlation with the Jurassic sequence in Western Australia. The Jurassic sequence in that state, in contrast to that of the Surat Basin, includes marine formations which are accurately dated by their contained faunas. In addition the microfloral studies of Balme (1957) have established the ranges of spore and pollen species, on the basis of the accurate dating of marine sediments within the succession.

The correlation indicated here is thus based on the ranges of species common to assemblages from Queensland and Western Australia. The most significant aspect of species distribution, as applied to correlation, is regarded as the first appearance of each spore and pollen species. Other aspects of distribution of the microfloras, such as relative abundance, and final disappearance of species, appear more likely to be affected by local conditions and so less reliable in correlation.

On the basis of first appearance, four species are considered to have fundamental importance in correlation. They are: *Inaperturopollenites turbatus* Balme, *Tsugaepollenites dampieri* (Balme) Dettmann, *Tsugaepollenites segmentatus* (Balme) Dettmann and *Contignisporites cooksonii* (Balme) Dettmann. Of these, *I. turbatus* and *T. segmentatus* are known from the oldest Jurassic microflora in Western Australia, that of the Cockleshell Gully Sandstone (Balme 1957, Tables 1 and 2B). This formation conformably underlies the marine Cadda Formation, of Middle Bajocian age. Thus the uppermost part of the Cockleshell Gully Sandstone must be regarded as Lower Bajocian (basal Middle Jurassic), but in view of the thickness of the formation (probably greater than 3,000 ft.—McWhae *et al.* 1958, p. 44) the lower part of the unit seems likely to extend down into the Liassic. *Tsugaepollenites dampieri* is recorded by Balme (1957, Table 3) from the Bajocian onwards, with doubtful specimens from the underlying Lower Jurassic. Finally, *Contignisporites cooksonii* appears later in the sequence. This species is absent from the Bajocian and earlier assemblages (Balme 1957, Table 3). As it is common in the Upper Jurassic (from Oxfordian onwards), it seems likely that it first appeared during the intervening Bathonian or Callovian. The species is recorded (Balme 1957, Table 2A) from sediments at a depth of 7,400 ft. in the Cape Range No. 2 well, for which faunal evidence suggests a Callovian age. This suggestion is based on a Lower Callovian age determination (Balme 1957, Table 1) for a sample from 7,830 ft. in this well. Thus the first appearance of this species is placed near the base of the Callovian.

The above conclusions regarding the ranges of these species in Western Australia are summarised below in Table 1:—

TABLE 1—DISTRIBUTION OF SELECTED SPECIES IN WESTERN AUSTRALIA

		I. turbatus	*T. segmentatus*	*T. dampieri*	*C. cooksonii*
UPPER JURASSIC	TITHONIAN				
	KIMERIDGIAN				
	OXFORDIAN				
MIDDLE JURASSIC	CALLOVIAN				
	BATHONIAN				
	BAJOCIAN				
LOWER JURASSIC	LIASSIC				

(Jurassic age units based on "Jurassic correlations in Western Australia" (McWhae *et al.* 1958); ranges of species based on Balme 1957, Table 3.)

The ranges of the same species in the Surat Basin sequence are indicated below in Table 2.

TABLE 2—DISTRIBUTION OF SELECTED SPECIES IN JURASSIC OF SURAT BASIN SEQUENCE

	I. turbatus	*T. segmentatus*	*T. dampieri*	*C. cooksonii*
BLYTHESDALE GROUP (in part)				
WALLOON FORMATION				
HUTTON SANDSTONE				
EVERGREEN SHALE				
PRECIPICE SANDSTONE				

(In the above table, and elsewhere in this paper, the term "Walloon Formation" is used for a lithologic unit so named in well completion reports of the Union Oil Development Corporation. It seems likely that this unit is lithologically equivalent to, and co-extensive with, the Walloon Coal Measures of the type area, although this has yet to be demonstrated in detail.)

From Table 2 it is clear that the sediments of the Precipice Sandstone and lower Evergreen Shale antedate the first appearance of *I. turbatus, T. segmentatus* and *T. dampieri.* There is thus strong evidence for a Liassic age for this part of the sequence, the possibility of an Upper Triassic age being ruled out by the presence of *Classopollis* which is not known from accurately dated pre-Jurassic sediments. Above this level the Hutton Sandstone is regarded as Upper Liassic to Bajocian. The first appearance of *C. cooksonii* near the top of the Walloon Formation is taken as equivalent in time to its first appearance near the base of the Callovian in Western Australia. These conclusions are summarised below in Table 3.

TABLE 3—AGES OF JURASSIC FORMATIONS (SURAT BASIN)

UPPER JURASSIC	TITHONIAN	BLYTHESDALE GROUP (in part)
	KIMERIDGIAN	
	OXFORDIAN	
MIDDLE JURASSIC	CALLOVIAN	WALLOON FORMATION
	BATHONIAN	
	BAJOCIAN	
LOWER JURASSIC	LIASSIC	HUTTON SANDSTONE
		EVERGREEN SHALE
		PRECIPICE SANDSTONE

The Middle Jurassic age indicated for the Walloon Formation in the Surat Basin necessitates a revision of the Lower Jurassic age previously assigned to the Walloon Coal Measures of the type area (de Jersey 1959). Stratigraphic evidence suggests that the sections are lithologically equivalent, and may be co-extensive, while microfloral evidence indicates that they are approximate time equivalents. Drilling of numerous oil wells in the Surat Basin since 1959 has indicated the presence of as much as 1,400 feet of Jurassic sediments underlying the Walloon Formation. This, in itself, favours a Middle, rather than a Lower Jurassic age for the unit, and such a conclusion is supported by a re-interpretation of the microfloral evidence, on the basis of the first appearance of selected species, as indicated above.

It should be noted that the above discussion has been based largely on data from the sub-surface of the Moonie and adjacent areas. However, the formations concerned are regarded as lithologically persistent between the sub-surface and outcrop areas and the available evidence suggests there is no major diachronism in the known extent of the units.

Evidence available on the age of formations in their type and outcrop areas, which supports the above discussion can be summarised as follows:—

(*a*) Precipice Sandstone.—Although no evidence is yet available on the palynology of the type area of the Precipice Sandstone, Evans (1964, p. 323) has recently reported a Lower Jurassic microflora from his unit in outcrop near Baffle Creek Homestead. There is strong field evidence of lithological continuity between this outcrop and that in the type area of the formation. Sub-surface data, however, indicating a Lower Jurassic age for the formation have been available for some years; the first published reference to such evidence was made by Moran and Gussow in a paper to the sixth World Petroleum Congress, 1963 (subsequently appearing in condensed form in *World Oil,* September 1963). The Lower Jurassic age assigned to the unit by Moran and Gussow was based on unpublished microfloral evidence of the present authors (de Jersey and Dearne 1961 and de Jersey and Paten 1963).

(*b*) Evergreen Shale.—The microflora of samples from this formation in outcrop in the general region of the type area is closely comparable with assemblages from the unit in the sub-surface of the wells studied. Consequently, the Lower Jurassic age assigned above is also applicable to the type area of the unit.

(*c*) Hutton Sandstone.—No evidence is yet available on the microflora of the type area of the Hutton Sandstone. Material is currently being examined from shallow drill holes in the outcrop of the formation close to the type area.

(*d*) Walloon Formation.—As indicated above, the writers have followed geologists of the Union Oil Company in applying this name to the unit in the sub-surface. There is evidence for lithologic continuity of this formation to the outcrop area where it has been recorded under the name of Injune Creek Beds. Samples studied from the Injune Coal Mine adjacent to this outcrop area yielded assemblages closely comparable with those from the Walloon Formation of the sub-surface.

(*e*) Blythesdale Group. No evidence is yet available on microfloras from outcrop areas of the group.

6. ACKNOWLEDGMENTS

The writers wish to acknowledge assistance from the geological staff of the Union Oil Development Corporation and Phillips Petroleum Company, who have submitted numerous cores for palynological examination. They are also indebted to Dr. G. Playford and his wife (formerly Miss M. Dettmann), of the Geology Department, University of Queensland, who kindly made available the manuscript of their recent paper (on the microflora of the Leigh Creek Coal Measures) and gave helpful advice on taxonomic problems. Miss M. Hamilton, of the Palynology Section of the Geological Survey, assisted in preparation of the photomicrographs.

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EXPLANATION OF PLATES

PLATE 1

(All photographs approximately X1000)

Figure 1.—*Stereisporites antiquasporites* (Wilson and Webster) Dettmann (Distal focus).

Figure 2.—*Stereisporites antiquasporites* (Wilson and Webster) Dettmann (Proximal focus).

Figure 3.—*Annulispora microannulata* de Jersey (Distal focus).

Figure 4.—*Annulispora folliculosa* (Rogalska) de Jersey (Distal focus).

Figure 5.—*Lycopodiumsporites rosewoodensis* de Jersey (Distal focus).

Figure 6.—*Lycopodiumsporites austroclavatidites* (Cookson) Potonié (Proximal focus).

Figure 7.—*Lycopodiumsporites austroclavatidites* (Cookson) Potonié (Distal focus).

Figure 8.—*Baculatisporites comaumensis* (Cookson) Potonié (Proximal focus).

Figure 9.—*Baculatisporites comaumensis* (Cookson) Potonié (Distal focus).

Figure 10.—*Tripartina* cf. *T. variabilis* Maljavikina (Median focus).

Figure 11.—*Matonisporites* sp. (Proximal focus).

Figure 12.—*Matonisporites* sp. (Proximal focus).

PLATE 2

(All photographs approximately X1000)

Figure 1.—*Foraminisporis tribulosus* Playford and Dettmann (Proximal focus).

Figure 2.—*Foraminisporis tribulosus* Playford and Dettmann (Distal focus).

Figure 3.—*Foveotriletes parviretis* (Balme) Dettmann (Proximal focus).

Figure 4.—*Ischyosporites marburgensis* de Jersey (Median focus).

Figure 5.—*Cadargasporites baculatus*, n. sp. (Holotype, polar view, proximal focus).

Figure 6.—*Cadargasporites baculatus*, n. sp. (Holotype, polar view, proximal focus).

Figure 7.—*Cadargasporites baculatus*, n. sp. (Holotype, polar view, distal focus).

PLATE 3

(All photographs approximately X1000)

Figure 1.—*Cadargasporites baculatus*, n. sp. (Polar view, proximal focus).

Figure 2.—*Cadargasporites baculatus*, n. sp. (Polar view, distal focus).

Figure 3.—*Cadargasporites baculatus*, n. sp. (Oblique lateral view).

Figure 4.—*Cadargasporites granulatus*, n. sp. (Polar view, proximal focus).

Figure 5.—*Cadargasporites granulatus*, n. sp. (Holotype, polar view, proximal focus).

Figure 6.—*Cadargasporites granulatus*, n. sp. (Holotype, polar view, distal focus).

Figure 7.—*Cadargasporites granulatus*, n. sp. (Polar view, distal focus).

PLATE 4

(All photographs approximately X1000)

Figure 1.—*Cadargasporites reticulatus*, n. sp. (Holotype, polar view, proximal focus).

Figure 2.—*Cadargasporites reticulatus*, n. sp. (Holotype, polar view, equatorial focus).

Figure 3.—*Cadargasporites reticulatus*, n. sp. (Holotype, polar view, distal focus).

Figure 4.—*Cadargasporites reticulatus*, n. sp. (Polar view, proximal focus).

Figure 5.—*Cadargasporites reticulatus*, n. sp. (Polar view, equatorial focus).

Figure 6.—*Cadargasporites reticulatus*, n. sp. (Polar view, distal focus).

PLATE 5

(All photographs approximately X1000)

Figure 1.—*Cadargasporites reticulatus*, n. sp. (Equatorial view).

Figure 2.—*Staplinisporites caminus* (Balme) Pocock (Median focus).

Figure 3.—*Polycingulatisporites crenulatus* Playford and Dettmann (Median focus).

Figure 4.—*Cingulatisporites saevus* Balme, Emend. (Median focus).

Figure 5.—*Cingulatisporites saevus* Balme, Emend. (Median focus).

Figure 6.—*Cingulatisporites saevus* Balme, Emend. (Median focus).

Figure 7.—*Polycingulatisporites mooniensis*, n. sp. (Holotype).

Figure 8.—*Polycingulatisporites mooniensis*, n. sp.

Figure 9.—*Polycingulatisporites mooniensis*, n. sp.

Figure 10.—*Duplexisporites gyratus* Playford and Dettmann (Median focus).

Figure 11.—*Nevesisporites vallatus*, n. sp. (Holotype, proximal focus).

Figure 12.—*Nevesisporites vallatus*, n. sp. (Holotype, distal focus).

Figure 13.—*Nevesisporites vallatus*, n. sp. (Proximal focus).

Figure 14.—*Nevesisporites vallatus*, n. sp. (Distal focus).

Figure 15.—*Nevesisporites vallatus*, n. sp. (Proximal focus).

PLATE 6

(All photographs approximately X1000)

Figure 1.—*Nevesisporites vallatus*, n. sp. (Proximal focus).

Figure 2.—*Nevesisporites vallatus*, n. sp. (Proximal focus).

Figure 3.—*Vitreisporites pallidus* (Reissinger) Nilsson.

Figure 4.—*Alisporites lowoodensis* de Jersey.

Figure 5.—*Alisporites australis* de Jersey.

Figure 6.—*Indusiisporites parvisaccatus* (de Jersey) de Jersey.

Figure 7.—*Alisporites* sp. 1 de Jersey 1962.

Figure 8.—*Indusiisporites parvisaccatus* (de Jersey) de Jersey.

Figure 9.—*Perinopollenites elatoides* Couper.

Figure 10.—*Perinopollenites elatoides* Couper.

PLATE 7

(All photographs approximately X1000)

Figure 1.—*Classopollis classoides* (Pflug) Pocock and Jansonius (Polar view, proximal focus).

Figure 2.—*Classopollis classoides* (Pflug) Pocock and Jansonius (Polar view, distal focus).

Figure 3.—*Classopollis classoides* (Pflug) Pocock and Jansonius (Equatorial view).

Figure 4.—*Classopollis simplex*, n. sp. (Holotype, polar view).

Figure 5.—*Classopollis simplex*, n. sp. (Polar view).

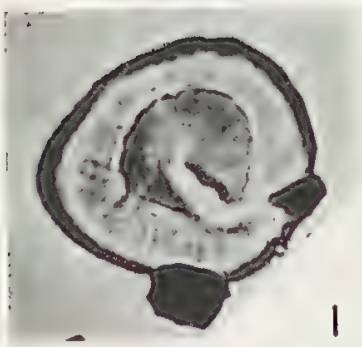
Figure 6.—*Classopollis simplex*, n. sp. (Slightly tipped laterally).

Figure 7.—*Podosporites* sp.

Figure 8.—*Tsugaepollenites dampieri* (Balme) Dettmann.

Figure 9.—*Tsugaepollenites segmentatus* (Balme) Dettmann.

Figure 10.—*Tsugaepollenites trilobatus* (Balme) Dettmann.



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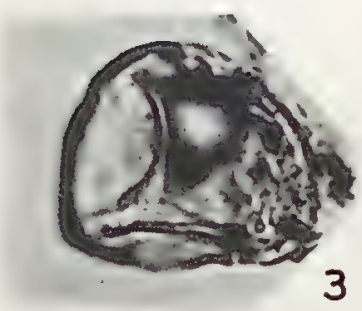

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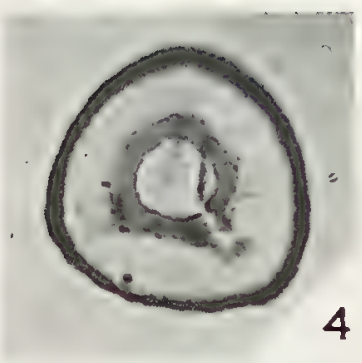

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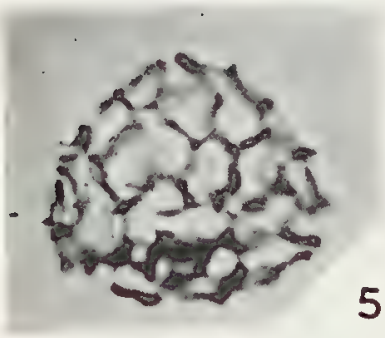

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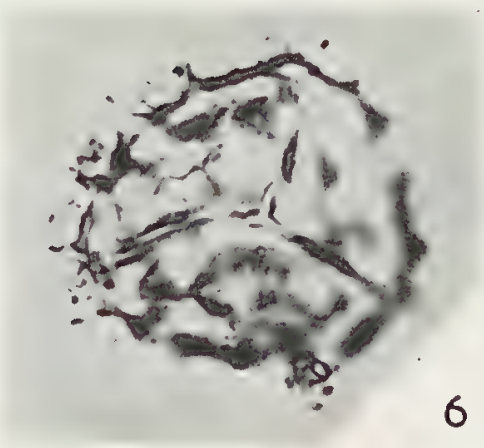

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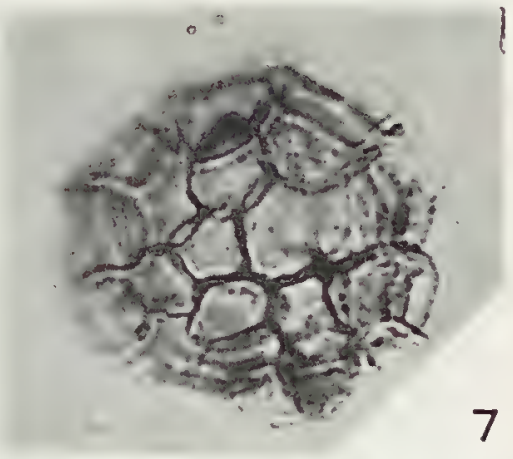

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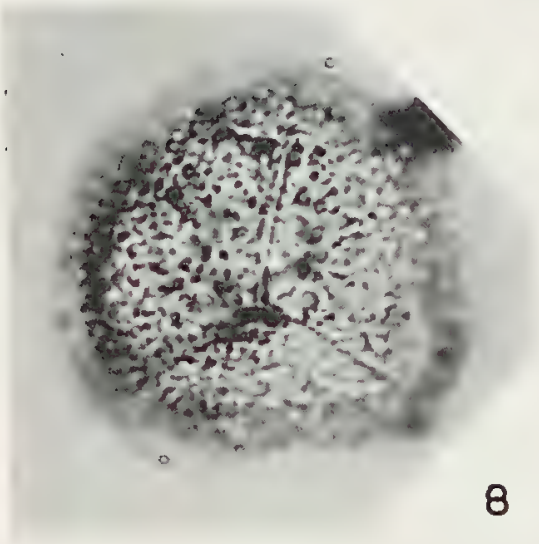

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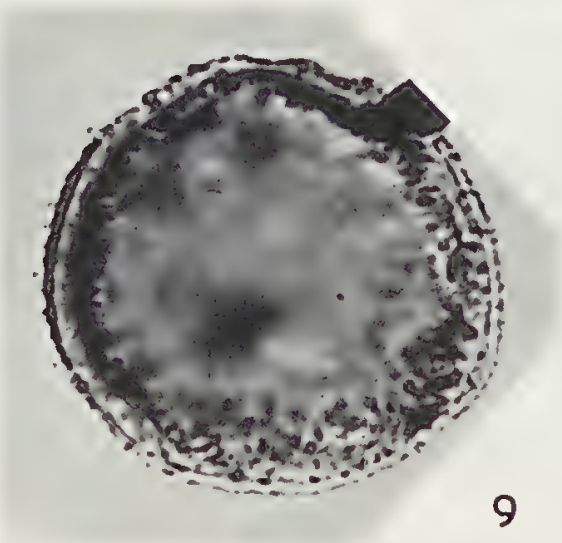

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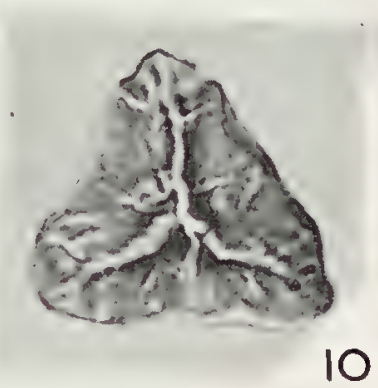

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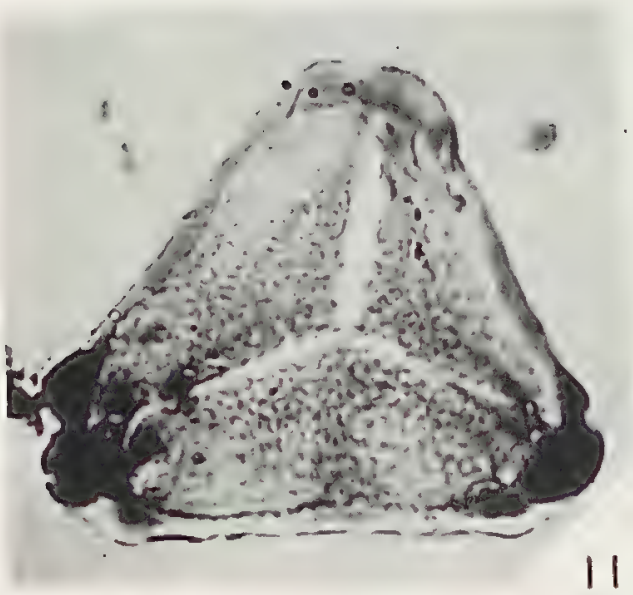

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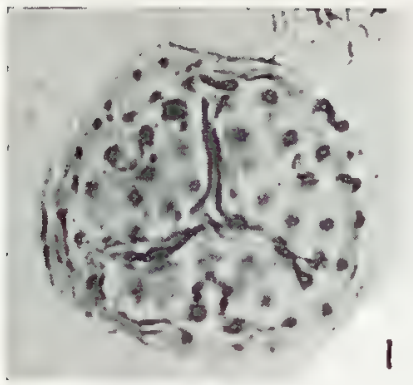
PLATE 1



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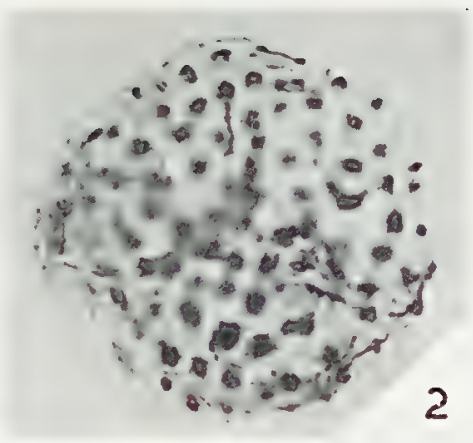

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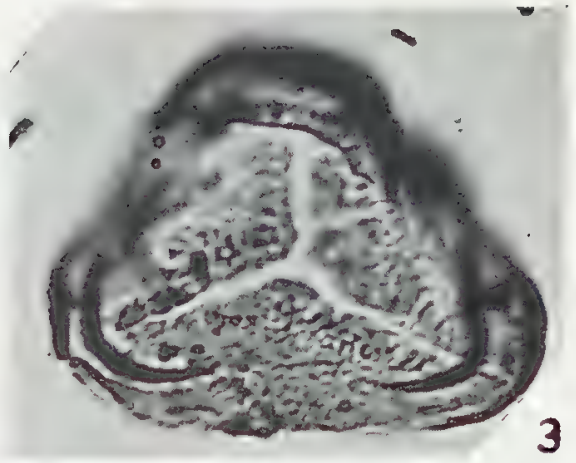

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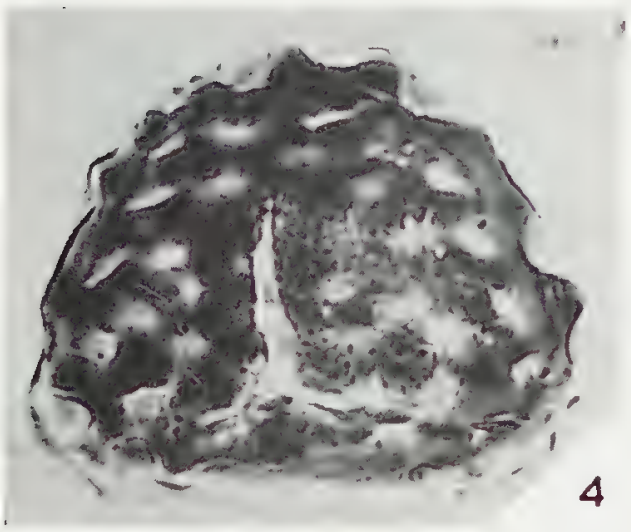

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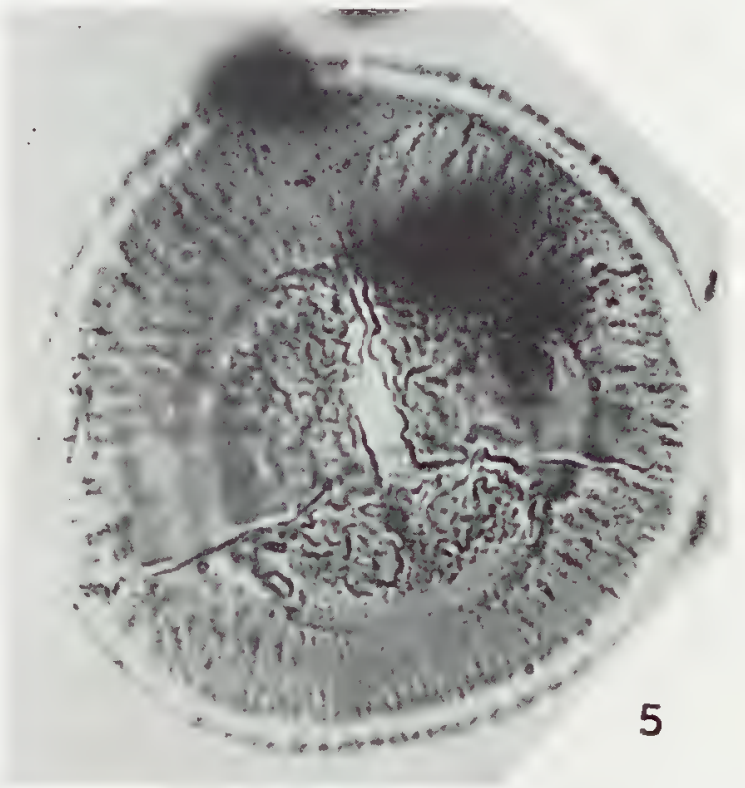

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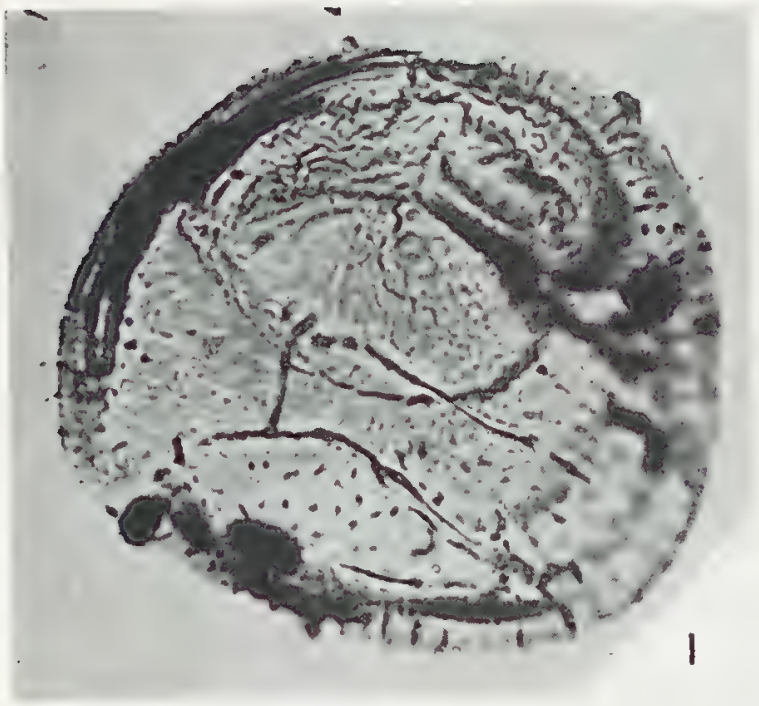
PLATE 2



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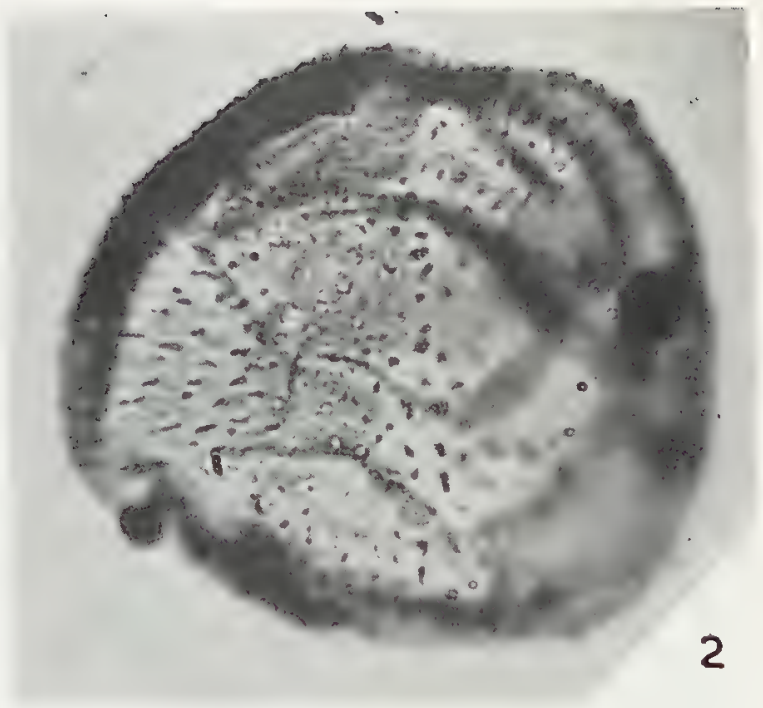

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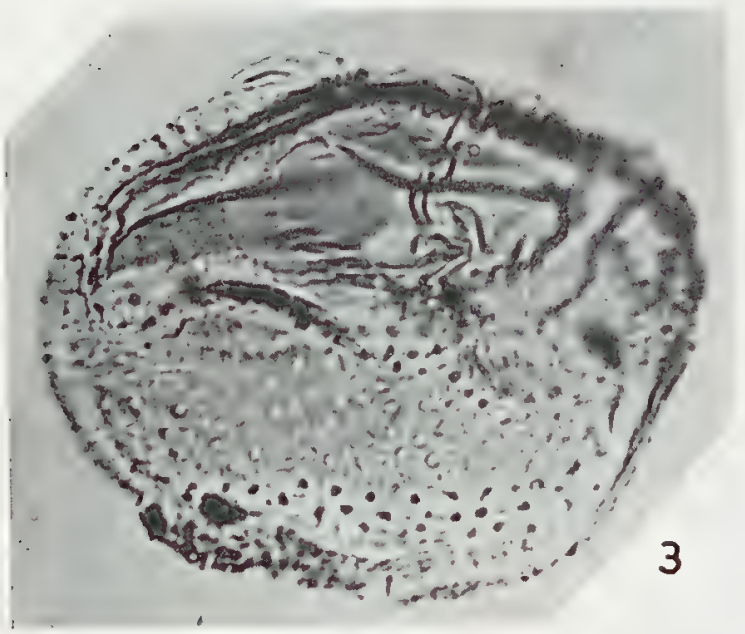

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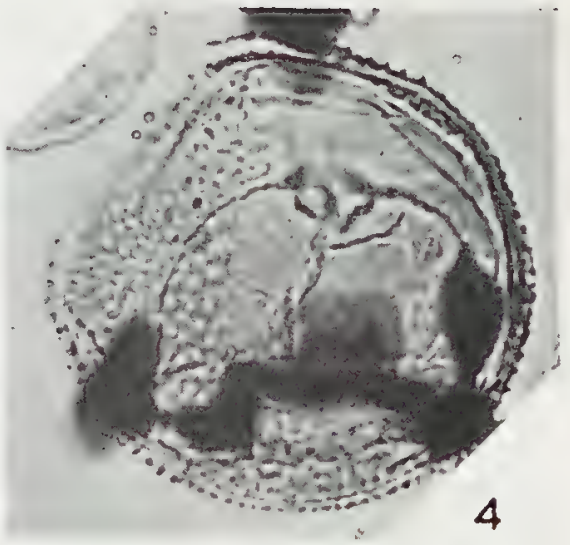

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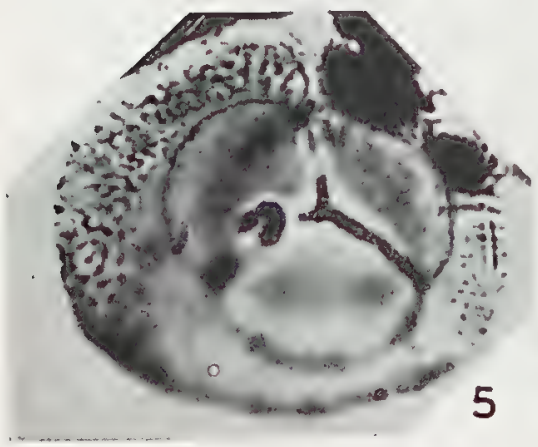

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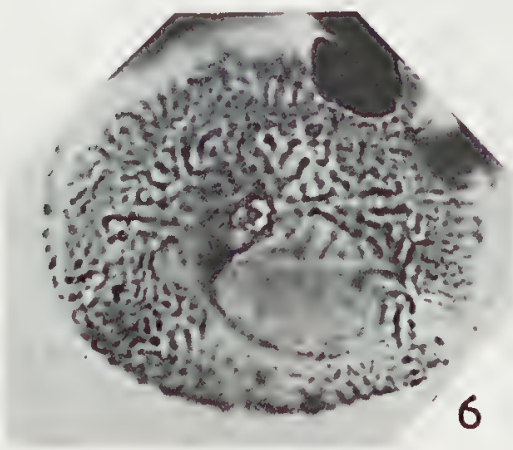

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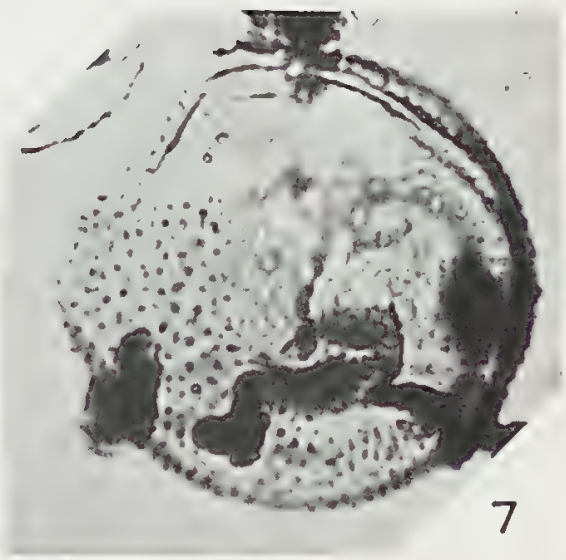

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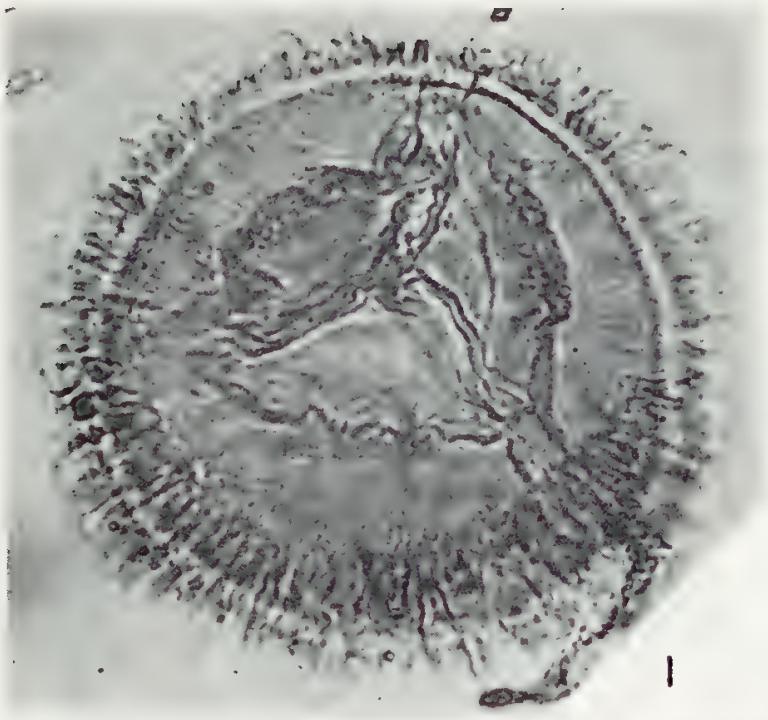

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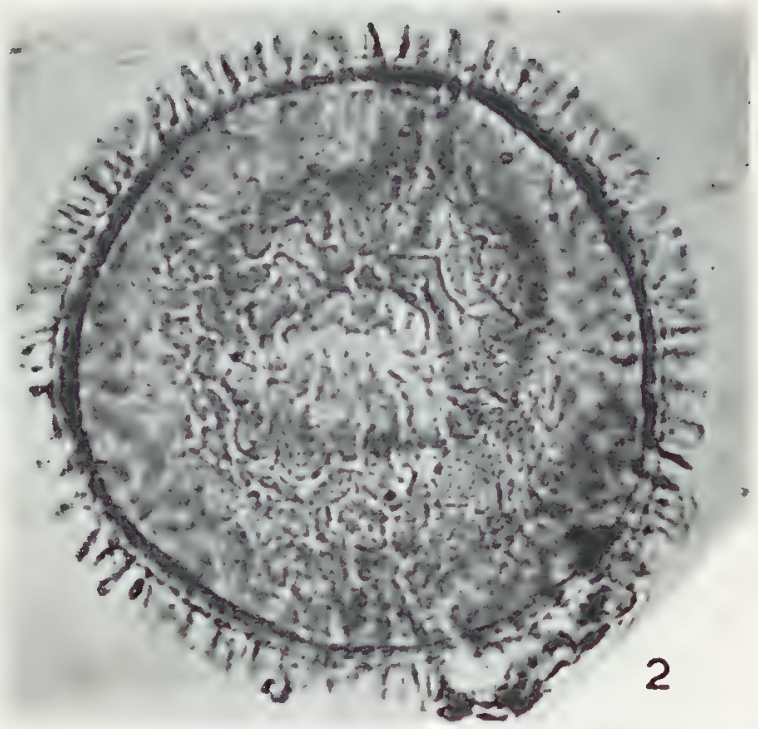

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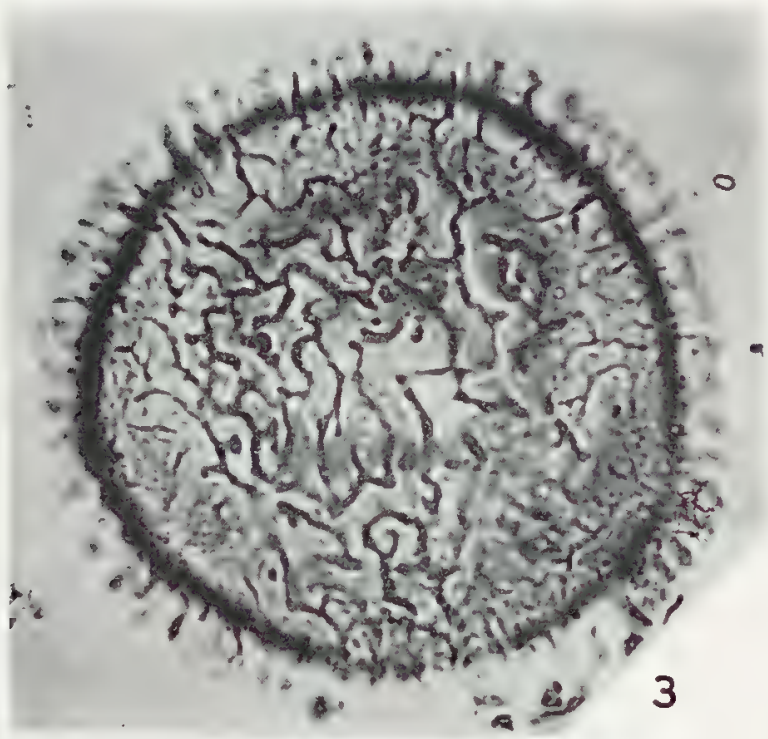

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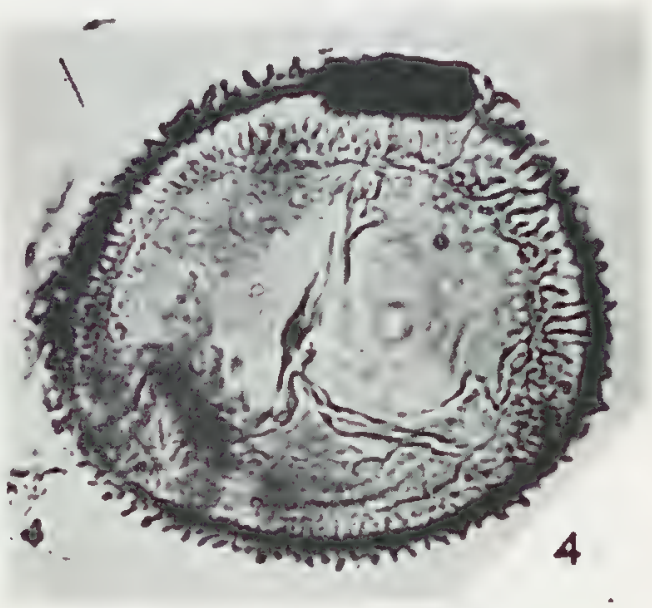

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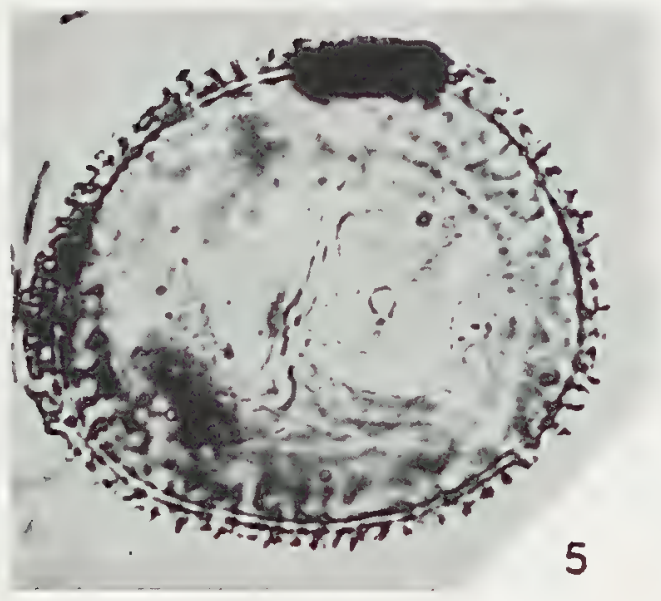

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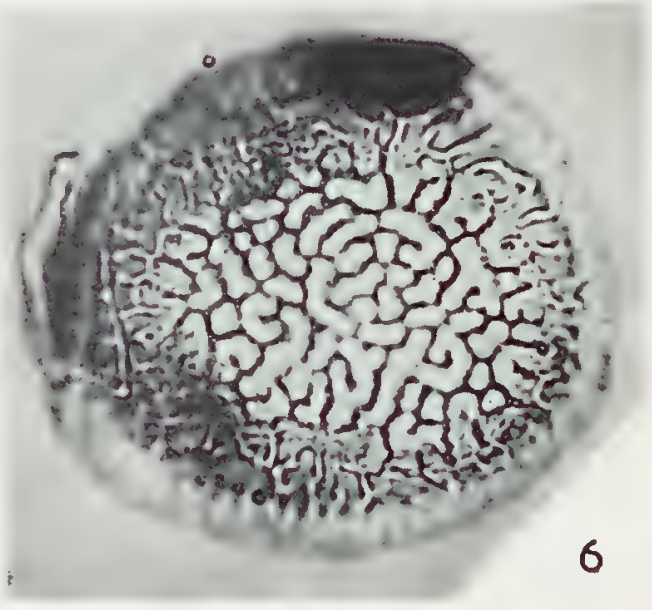

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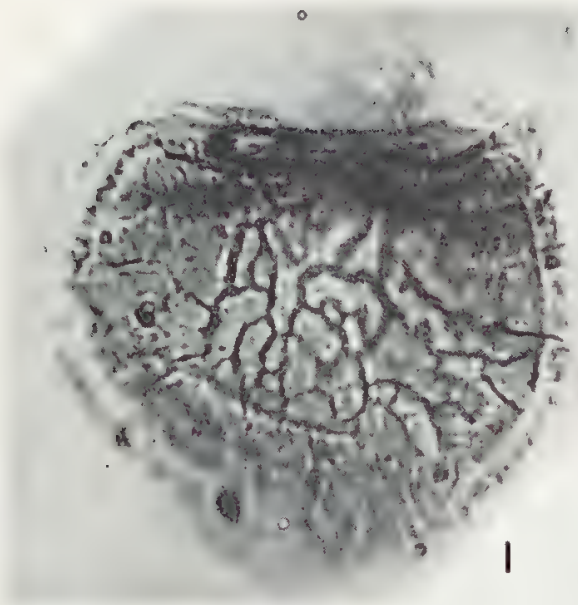
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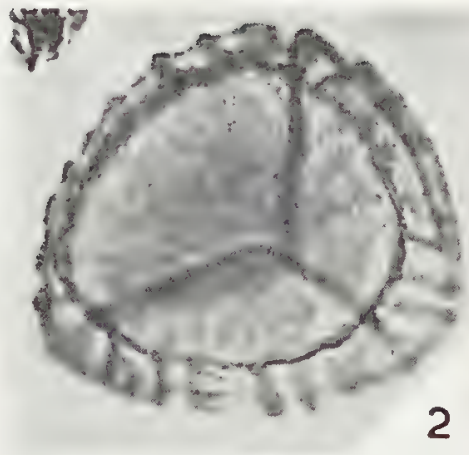
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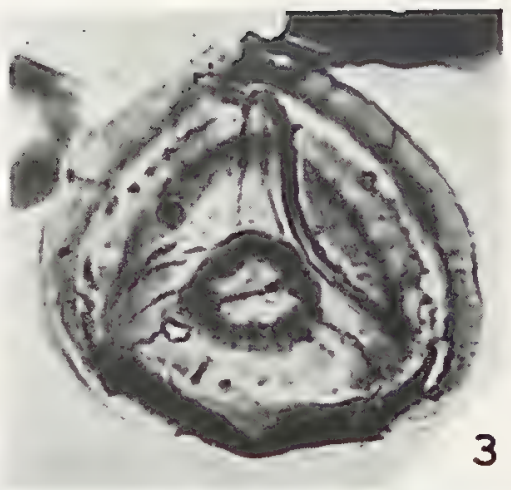
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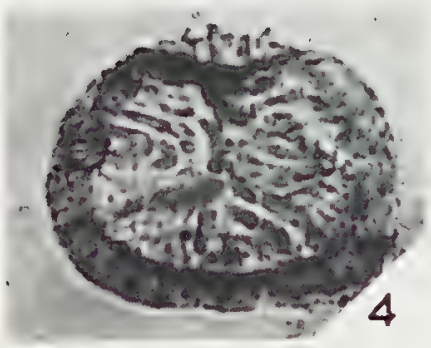
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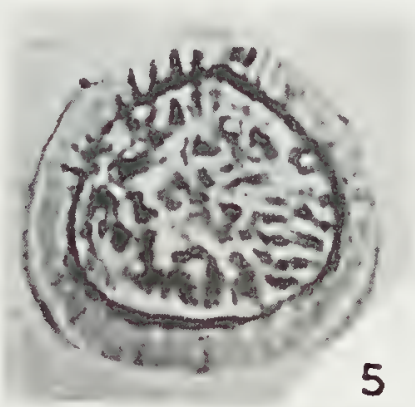
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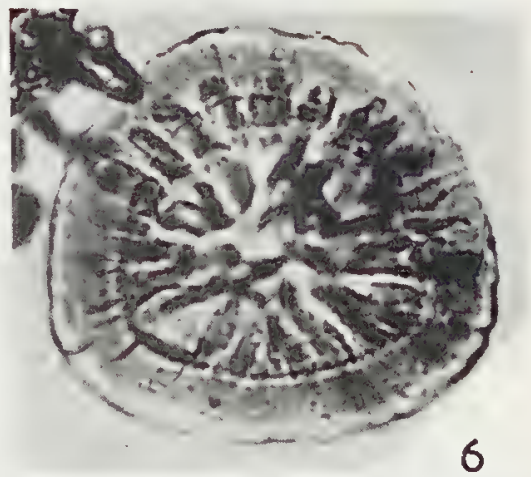
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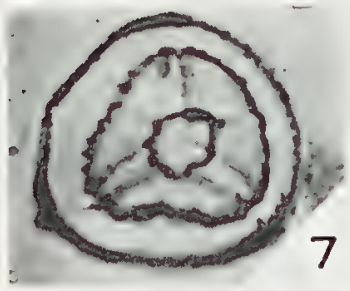
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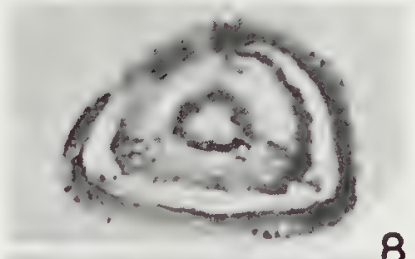
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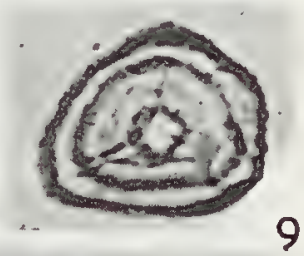
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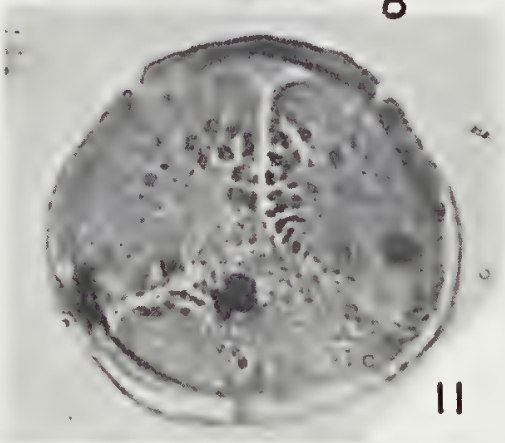
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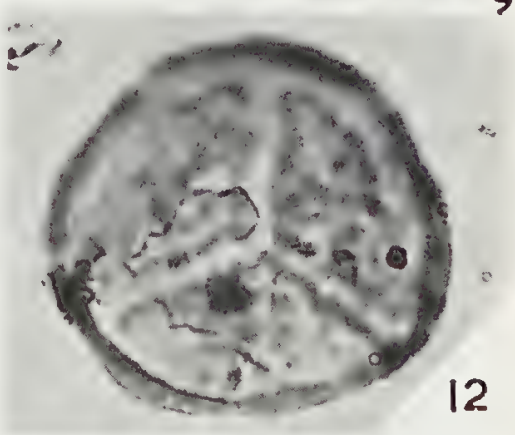
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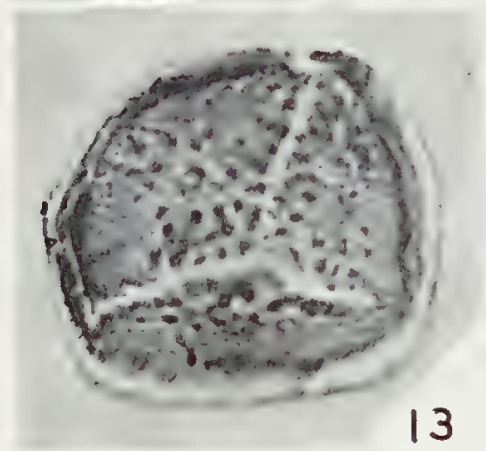
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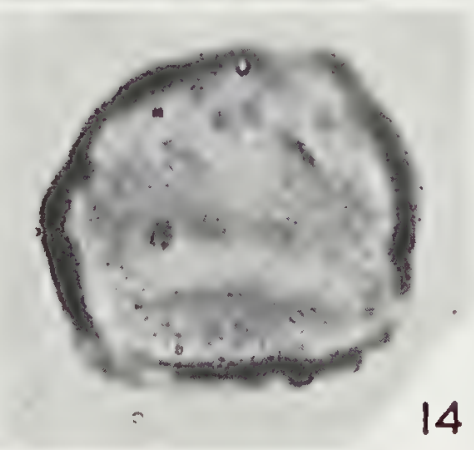
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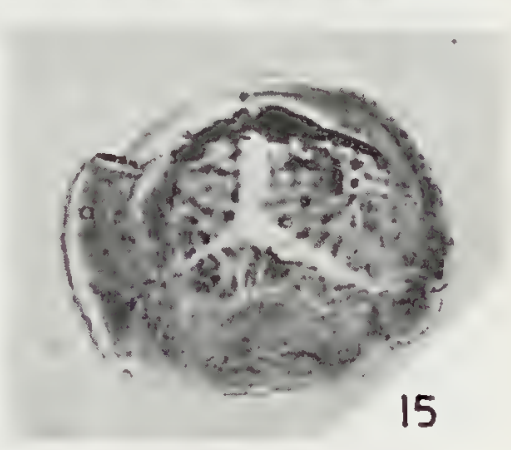
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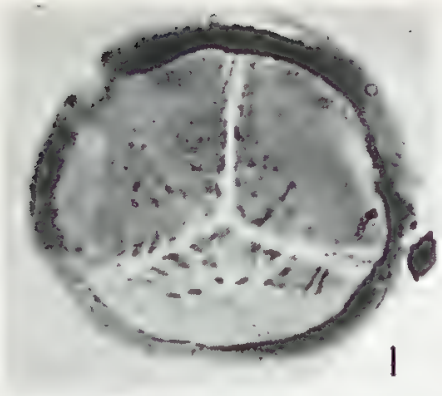
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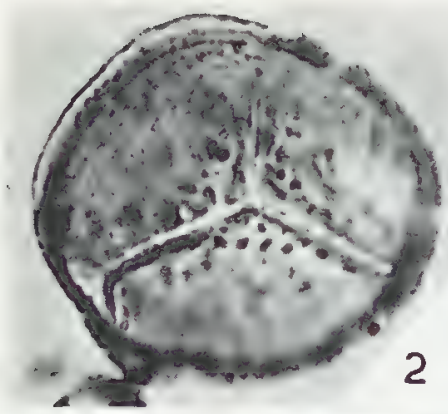
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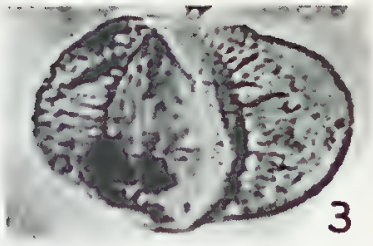
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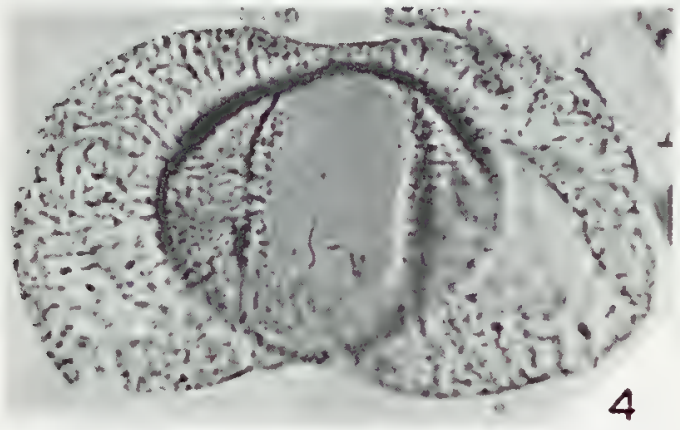
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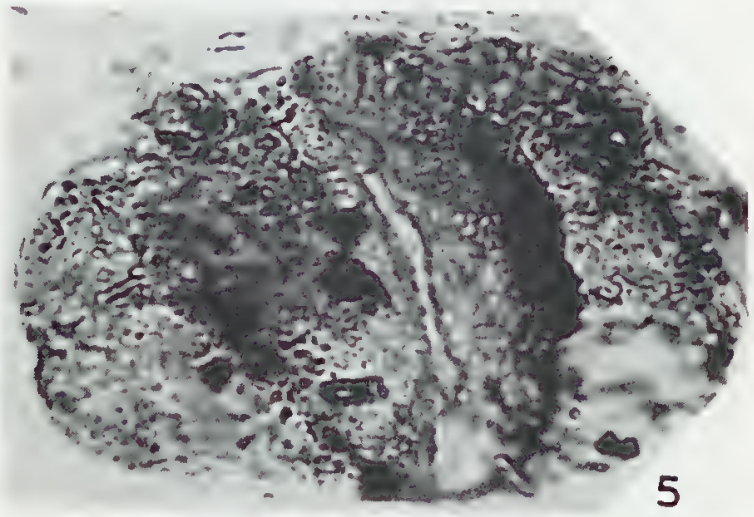
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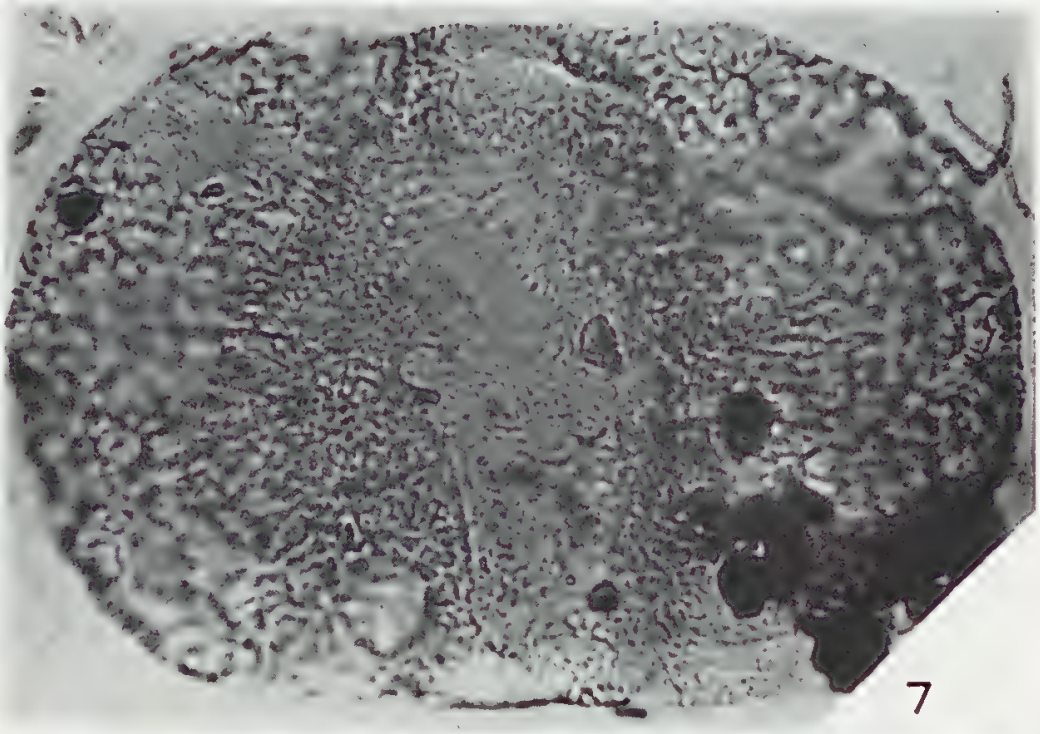
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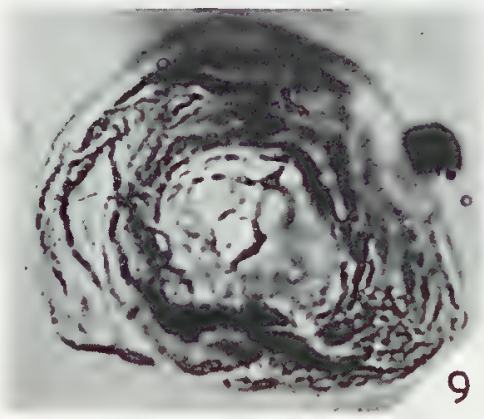
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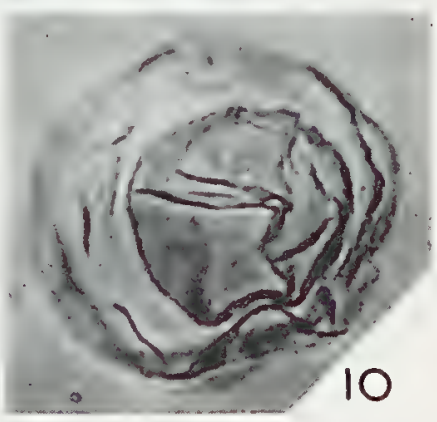
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PLATE 6

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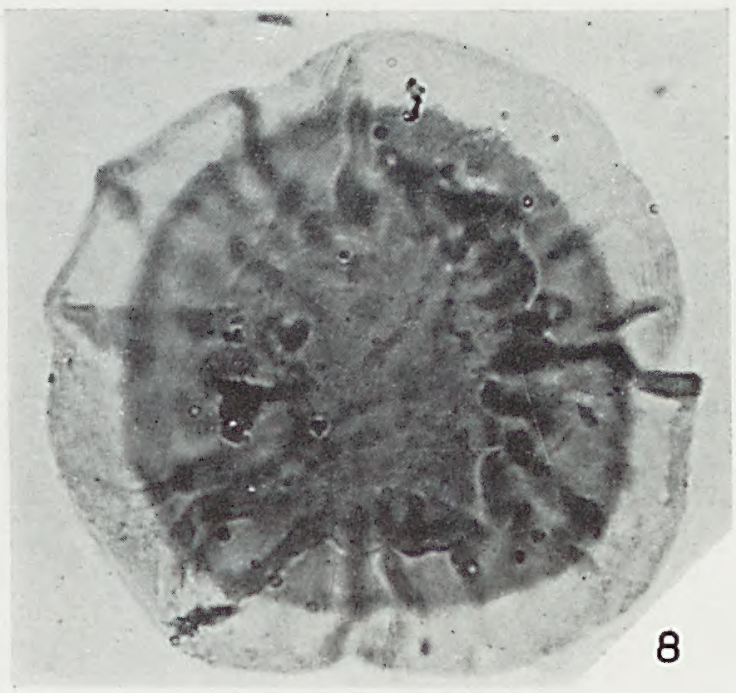
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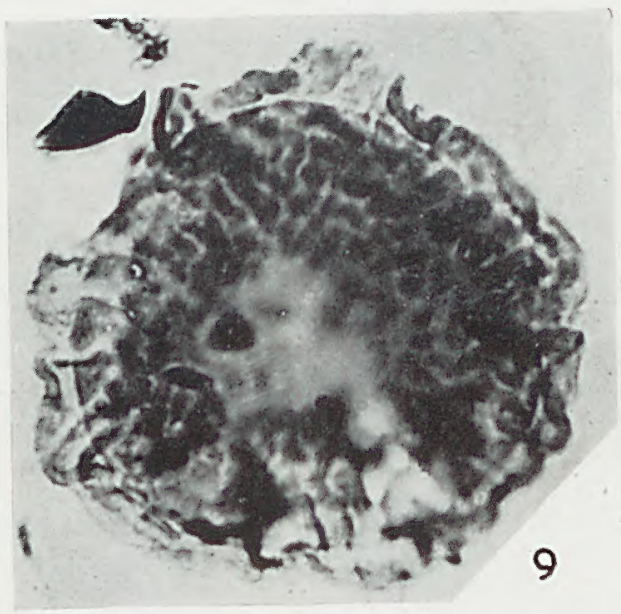
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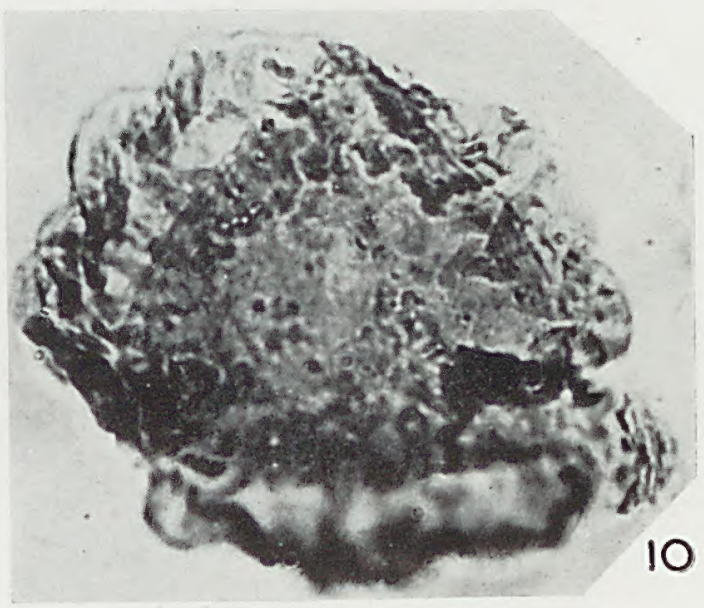
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PLATE 7

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